The Intertidal Biota of Puget Sound Gravel Beaches

Part 1. Spatial and Temporal Comparisons between 1999 and 2000

Part 2. Recommendations for Future Sampling

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Executive Summary

This project continued our study of spatial and temporal variability of shoreline biota in the South and Central Puget Sound Basins. Sampling done in summer 2000 focused on quantifying interannual variation among biota, and testing the stability of the north-south negative trend in species diversity seen in the more extensive 1999 sampling. Preliminary data from our 1999 intertidal surveys of pebble beaches suggested that wave energy gradients along the axis of Puget Sound affect community structure by forcing the removal of fine sediments. In June 2000, we resampled 21 pebble beaches from the original 45 sampled in 1999, to compare data among years. We retained the nested sampling design in order to compare within and among different spatial scales. In each of 7 areas, the biota from three replicate beaches were sampled in the low zone along a 50 meter horizontal transect. The 7 areas consisted of three bays in the southern basin of Puget Sound, and four circulation cells in the central basin. Replicate beaches were selected based on similarity of the geomorphic form, sediment size, slope angle, aspect, wave energy, surface roughness, and pore water chemistry. Data on mean annual water temperature, salinity, air temperature, precipitation, and wind speed and direction were also used to compare basin scale differences. Biota were sampled using standard quadrat and core techniques. All macroscopic algae and invertebrates were identified and abundances were estimated.

In 2000, we found a total of 123 taxa in 210 quadrats and cores (21 sites), as opposed to 150 taxa in 1999 from those same sites (we found a total of 230 taxa from all 48 sites sampled in 1999). Of the 178 combined taxa found in both years, 110 taxa were observed in both years, while 15 were found only in 2000, and 44 were found only in 1999. Species richness generally decreased from north to south, with a greater decrease observed in quadrat samples compared to core samples. Annelids, molluscs, arthropods, and rhodophytes represented 85% of the observed taxa. Non-metric ordinations were used to compare community structure among all samples collected in 1999 and 2000. We found that an along axis trend in community structure was present in both years. There is correlative evidence suggesting that higher wave energy decreases the amount of small sediments in the northern beaches. Our data show a high degree of similarity among the communities from replicate beaches within a bay (south basin) or a circulation cell (central basin). This similarity could be due to larval retention within these areas, and/or a higher degree of physical similarity among beaches that are close together. There was a significant change in the communities between the 1999 and 2000 samples. There was a greater difference between years in the central basin than in the southern basin, but no clear explanation for this pattern. There is some evidence suggesting that an increased number of amphipods were sampled in 2000 in the Central Basin. Differences among communities are much greater spatially than temporally. The observed spatial differences were highly correlated to measured physical properties of the beaches whereas the observed temporal shifts have no clear explanation from the current dataset.

We recommend that future sampling incorporate a mix of high-resolution sampling, as has been done to date, and lower-resolution sampling that will save time and taxonomic expertise. All surface-quadrat sampling should continue to be done at the ‘high-

resolution' level for consistency among sites and years; this should be possible with minimal additional training for DNR personnel. Infaunal identifications in some future years should be able to consist of lower-resolution, family-level work, since in many cases family-level identifications allow researchers to see the same patterns as species-level work. At regular intervals (perhaps every 3-5 years), higher-resolution sampling should be conducted on these beaches to look for trends in species diversity. We recommend that all the beaches sampled in 2001 (by DNR and by UW/OSU personnel) be sampled at the same, high-resolution level to allow a full 3-year temporal comparison of the biota at these beaches

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Introduction

Benthic organisms within estuarine and marine nearshore ecosystems are sensitive to environmental gradients and may serve as indicators of changes occurring in the coastal ocean (Warwick and Clarke, 1993). These organisms may have life spans ranging from days to seasons or years, and they frequently occur in large numbers, thus providing an attractive baseline for statistical analyses. For these reasons, and because of logistical accessibility, detecting change in nearshore biological communities is a key component of experimental ecological research and applied monitoring programs.

The ecological linkages between the nearshore ocean and the benthos are poorly understood. For example, production in some intertidal communities may be regulated by the delivery of nutrients from the ocean or by nutrients delivered from nearby rivers and estuaries, larval recruitment may be regulated by coastal current patterns, and wave energy may structure communities by direct forces on organisms or through sediment transport processes. However, it is clear that there is strong physical and biological coupling between the nearshore and intertidal habitats. Such “edge” communities at the transition between one regime and another may provide a rare opportunity to study linkages and how changes in the environment can affect those linkages.

Our ongoing study in the Southern and Central basins of Puget Sound (Schoch and Dethier 1997, 1999, Dethier and Schoch 2000) seeks to quantify these linkages while characterizing the shoreline biota, and assessing its spatial and interannual variability. Ultimately, we hope to be able to explain much of the variation seen in shoreline communities by the geophysical differences among them, allowing us to then assess the impacts of other (including anthropogenic) events. In 1999 we performed an extensive sampling of pebble beaches in numerous oceanographic cells from southern to north-central Puget Sound, and found clear north-south trends in diversity and various physical parameters. In 2000 we resampled a subset of these sites to test for interannual variation and to see if the north-south trends persisted from year to year. Part 1 of this report presents the results of the data analysis. Part 2 presents the results of a literature review on potential methods for lower-resolution sampling, and provides recommendations for a system to test in 2001.

Part 1: Temporal and Spatial Analyses of 1999 and 2000 data

Methods

Our approach for increasing the statistical power of comparisons among communities and populations from intertidal beaches is to decrease the physical variability among sample sites by selecting a series of replicate beaches based on the physics and physical structure of the shoreline. We segment complex biogeochemical shoreline gradients using a combination of qualitative and quantitative partitioning criteria. Previous studies have often failed to develop quantitative links between specific intertidal assemblages and physical attributes of habitats, thus making it impossible to “scale up” in either time or space from limited *in situ* sampling (Menge et al., 1997). This method addresses the needs of coastal ecologists seeking to make comparisons among spatially independent beach sites. This method relies on the quantification of physical features known to cause direct and indirect biological responses, and uses these as criteria for partitioning complex shorelines into a spatially nested series of physically homogeneous segments. For example, at the spatial scales of bays and inlets in Puget Sound, geophysical parameters such as sediment grain size, wave energy, substrate dynamics, and pore water chemistry are quantified. At large spatial scales such as within the basins of Puget Sound, water chemistry attributes such as temperature and salinity are used to identify major oceanic climates. These nested segments can be used to study within-segment and among-segment variability, which in turn will support studies of the biotic and abiotic processes that control variability. Detailed descriptions of these methods have been presented in earlier reports.

Figure 1 shows the south and central basins of Puget Sound and the seven bays and nearshore cells that were chosen for this intertidal sampling project. In 1999, we sampled three sets of replicate beaches each in Budd Inlet, Case Inlet and Carr Inlet from the south basin (a 3 x 1 x 3 design). We also sampled three sets of three replicate beaches in each of four nearshore cells in the central basin (a 3 x 3 x 4 design). This nested design allowed us to compare the variability of community structure within and among the bays and cells and basins of Puget Sound. In 2000, we sampled each of the replicate beaches in Budd, Case and Carr Inlets of the south basin (3 x 1 x 3), but only one out of three sets of replicates in each of the cells of the central basin (3 x 1 x 4).

Samples were collected in the lower zone only (MLLW or 0 meters elevation). At this level the biota are diverse and therefore sensitive to changes in the marine environment. In addition, this low level is still subject to anthropogenic stressors from both land (when emersed) and sea (when immersed). We collected 10 random samples along a 50 m horizontal transect positioned near the center of the beach segment. Each sample consisted of quantifying surface macroflora and fauna abundance in a 0.25 m^2 quadrat, and infauna in a 10-cm diameter core dug to 15 cm depth. Percent cover was estimated for all sessile taxa in the quadrats, and all mobile epifauna were counted. Core samples were sieved through a 2 mm mesh and taxa were counted. All organisms not identifiable to the species level in the field were placed in formalin and identified in the lab. Taxonomic identifications for invertebrates were according to Kozloff (1987), and Gabrielson et al. (1989) for macroalgae.

Results

Figure 2a shows data from the National Weather Service (NWS) observation sites at Port Angeles, Everett, SeaTac Airport, and Olympia. Note that the mean annual air temperature shows little spatial variation along the axis of Puget Sound, but there is a two fold increase in the mean annual precipitation between the north and south end of the Sound. Figure 2b shows the spatial variation in tide range along the axis of the Sound. The mean high tide elevation at Olympia is twice as high as the same datum at Port

Angeles. Therefore, for any given beach at Port Angeles, a beach with the same slope angle will have approximately twice the surface area near Olympia.

Figure 3 illustrates the mean monthly variation of air temperature along the Sound. There does not appear to be a difference among the four NWS sites, and as expected the air temperature is highest during the months of July and August and lowest in December and January.

The mean sea surface temperature and salinity data at 2 meters depth for sites monitored by the Washington Department of Ecology were compared along the axis of Puget Sound for the last five years of observations (or the available period of record). The sites are shown on the map in Figure 4, and the data in Figures 5a and 5b. As expected, there is an increase in water temperature and a decrease in salinity from north to south along the axis of the Central and South Basins. Figures 6a and b show the data collected by boat transects in April 1999. These higher spatial density data show a phenomenon not evident from the DOE data, which are collected from single points along the axis of Puget Sound. We were interested in quantifying any across axis gradient in the bays and inlets of the South Basin and across the Central Basin. Our April 1999 data show a marked gradient in salinity (Figure 6b) across the Central Basin, but very little temperature gradient. This same pattern was measured in Budd, Case, and Carr Inlets in the South Basin. The survey transects were repeated in July 2000, but no clear pattern was evident. This may be due to the difference in survey dates. The earlier surveys of April 1999 may have picked up a signal from higher stream flows entering the Central Basin during the period of peak snowmelt. The lack of pattern in the later July survey of 2000 may result from lower summer flows following the spring rains and snow melt period. If across axis comparisons of beaches and beach biota are to be made in the future, then the salinity gradients need to be refined at every spatial scale in the South and Central Basins of Puget Sound.

Figure 7a shows the calculated wave energy for the sampled beaches as per Komar (1997), and explained in earlier reports. The wave energy on beaches in South Sound is about half the energy on beaches in the northern part of the central basin. Interestingly, as shown on Figure 7b, there are about two to three times as many sand sized substrate particles on the pebble beaches in the South Sound as on the Central Sound pebble beaches, and about 1.5 times more pebble sized substrate particles in the Central Sound as in the South Basin. Wave energy was regressed against substrate size and not surprisingly, the two parameters are highly correlated ($R^2 = .84$, $n = 7$ sites).

Pore water temperature and salinity measured in holes dug at the sampled beaches, are shown on Figure 8a and b. Pore water temperatures show a slightly positive trend from north to south with minimal variation within a site. The salinity data shows a slightly decreasing trend from north to south, but the within site variation is very high so that any conclusions about spatial trends are inappropriate.

In 2000, we found a total of 123 taxa in 210 quadrats and cores (21 sites), as opposed to 150 taxa in 1999 from those same sites (we found a total of 230 taxa from all 48 sites sampled in 1999). Of the 178 combined taxa found in both years, 110 taxa were observed in both years, while 15 were found only in 2000, and 44 were found only in 1999. About 30% of these taxa were observed in fewer than 10 samples. The identified taxa, their ranked frequency of observation (number of samples where any individuals were found), and trophic levels are shown in Table 1. The full dataset is given in Appendix A. As we observed in 1999, species richness shows a negative trend from north to south in both quadrat and core samples. These data are shown in Figure 9. Figure 10a shows the trophic distribution of the observed taxa. Deposit feeders, carnivores, suspension feeders, and primary producers are most characteristic of the pebble beach communities. Interestingly, herbivores are not well represented in these communities. Scavengers outnumbered herbivores by 2 to 1. In terms of phyla, annelids, molluscs, arthropods, and rhodophytes represent 85% of the observed taxa (Figure 10b). Figure 11 shows the trophic level groupings for the organisms found at each sample site. 34 taxa occurred on only a single beach (and nowhere else), and only 11 taxa were found on more than half of the sampled beaches. Only 2 groups of taxa were represented by at least one individual on every beach: barnacles, and bladed green algae.

Non-metric ordinations were used to compare community structure among all samples collected in 1999 and 2000. We found that an along axis trend in community structure was present in both sample years. Figure 12 shows the ordination results. The symbols represent the sampled communities from each quadrat/core combination with open symbols for those sampled in 1999 and the solid symbols in 2000. These data show a high degree of biological similarity among the replicate beaches within a bay (South Basin) or a circulation cell (Central Basin). Figure 13 is the same plot as Figure 12, but highlights the geographic distribution with polygons drawn around the samples collected from the same beach in each sample year. There was a significant difference between the 1999 and 2000 samples (p-value << .01), even though the along axis pattern is basically the same. There was a greater difference between the 1999 and 2000 samples in the central basin than in the southern basin, but there is no clear evidence from our data to explain this difference.

A divisive clustering technique, two-way indicator species analysis (TWINSPAN), was used to analyze the data for major biological divisions. This analysis showed that the first major division, or first major difference in all the observed communities, separated the communities along the north to south axis of Puget Sound. However, the division was not clearly related to a basin effect, since many of the samples from the southern portion of the Central Basin overlapped with those from the northern portion of the South Basin. Polygons were drawn over those samples identified by TWINSPAN and are shown on Figure 14 (same ordination plot as Figure 13). The taxa most responsible for this division are listed inside each polygon. These lists should be interpreted to mean that there were more individuals found of any listed taxa in the corresponding polygon than in the other polygon, and not necessarily that no observations of these taxa were made in the other polygon.

The second major biological division (Figure 15) split the data from the Central Basin roughly between the two sample years (1999 in tan and 2000 in red). However, the temporal change is not clearly evident in all cases. Some of the samples from Carkeek 2000, Possession 1999, and Brace 1999 overlap the two TWINSPAN polygons, indicating that no significant change occurred at these sites between the sample years. The second division of the TWINSPAN analysis provides some evidence suggesting that an increased number of highly mobile amphipods and hermit crabs were present in the 2000 samples from the Central Basin beaches.

The third major division, also shown on Figure 15, divided the Budd Inlet samples (yellow polygon) from the Case and Carr Inlet samples (purple polygon). Observe however that the Redondo 1999 (from the Central Basin) samples are also in the purple polygon and that the Carr 2000 samples span both polygons. These analyses suggest that the observed differences among communities are much greater spatially than temporally in the South Basin.

Figure 16 shows the same ordination plot as Figure 13 but with an overlay of vectors that represent the physical parameters most correlated to the observed patterns. The vectors are all aligned with the axis of Puget Sound with higher wave energy towards the north (and low energy towards the south), more cobbles in the substrate towards the north, more sand in the substrate towards the south, and higher precipitation and water temperatures towards the south. The measured physical attributes explain the variation along the axis of Puget Sound and the differences between the Central and South Basins, but do not explain the differences observed among the sample years. The taxonomic differences observed in the Central Basin among the sample years suggest that a biological shift occurred within the communities. This could be a real biological shift, a sampling artifact, or an artifact of taxonomic identification. The TWINSPAN analysis showed that there were more amphipods and hermit crabs observed in 2000 than in 1999. These organisms are highly mobile and not necessarily a stable member of the patch of ground sampled with a .25 m^2 quadrat.

Discussion

Our study has identified the spatial patterns and physical causes of variation in the pebble beach marine communities of Puget Sound. The temporal variation is the subject of on-going work, but the TWINSPAN analysis has identified the taxa most variable between the 1999 and 2000 sample years. In some cases this variability can be explained, such as with amphipods and hermit crabs. In other cases this variability may be an indication of a more significant change or shift occurring in the biological community as a response to a greater natural and anthropogenic forcing. However, without knowing what that forcing is, we are left with an observed change but no clear mechanism(s) to explain that change. Our study has shown how important it is to quantify the natural spatial variability of beach communities in Puget Sound, and we are beginning to accumulate evidence for natural changes that can be expected in the biological communities over time from non-spatial forcing. We have also shown that pebble beach communities have a high degree of fidelity to specific combinations of small spatial scale physical forcings, so that predictions can be made about what communities can be expected in different places in

Puget Sound. This has important implications for baseline data and damage assessments, as well as for making predictions about what communities can be expected on beaches not actually sampled but where the important physical forcing mechanisms can be quantified.

In terms of monitoring for a change in the intertidal biota, it is clear from our study that both the physical and biological components of the system need to be monitored over time in order to provide us with sufficient variables to explain observed changes. Our data, consisting of a single sample per year, are apparently adequate to explain the spatial variability observed in the data, but we do not know much about what causes the temporal changes. We know that physical conditions of the habitat play an important role in structuring the communities. But what physical changes occur in the habitat that we do not observe over the course of the year? It is likely, for example that wave energy increases in the winter, and since this is highly correlated to substrate size, it is also likely that more fines are in suspension during the winter than during the summer, particularly following erosional events. More disconcerting is that we do not know much about the temporal variability of wind driven surface currents, and the patterns of water circulation at the scale of beaches or even at the scale of bays. We learned from the data that differences occur in the biota at scales of bays and inlets in the South Basin, and of circulation cells in the Central Basin. But we have not yet studied important aspects of the natural system. For example, where do the larvae come from? Where do they go? What are the rates of recruitment to adult populations? Perhaps most importantly, what are the factors that control recruitment to pebble beaches?

With that noted, the power of this dataset has not been fully developed. With an additional year on the time series, we can begin to do power analyses on individual taxa to evaluate which organisms, or group of organisms, are most appropriate to sample with the objective of change detection over time and space. This would narrow our focus down to perhaps just a few key players in pebble beach communities. At this point a key issue that remains unresolved is to determine the important spatial, temporal and taxonomic scales of change. We have seen that few organisms occur on all beaches in the Sound. When an organism does not occur (or is not sampled) on a beach, then it is no longer an indicator of the health of that habitat. So if we restrict ourselves to using the abundance of a particular taxon as an indicator of habitat health, our indicator taxon loses its usefulness when it reaches zero abundance. Natural spatial variability within the sound can cause this without any evidence of an unhealthy habitat. We have seen that a Puget Sound scale evaluation of habitat health would have to rely on a barnacle index, one of the few species that occurs everywhere, but this may not be very meaningful in light of recruitment failures, freezing events, etc. Therefore, monitoring for a change may rely on a different set of organisms for different areas of the Sound. Similarly, the taxonomic resolution required to detect a change may also vary in different areas of the Sound. Table 1 is useful for the discussion about which taxa are most meaningful at different scales and taxonomic resolutions. The organisms have been arranged according to the number of observations made per year (i.e. the number of quadrats the organism was observed for each year). Also listed are the rank order (from highest to lowest for year 2000) of each organism according to the number of times it was seen. It is interesting to note how the organisms we observed change in rank from 1999 to 2000. The number of times, or frequency an organism was observed is an indication of how spatially uniform the distribution of an organism is at any time. Lower frequencies indicate more patchiness, and therefore these organisms are less likely to tell us much about Sound-wide changes. There are columns showing which organisms were observed in each year. These are interesting to compare to see which organisms are temporally stable and which are either temporally patchy or are not being sampled consistently. Following the “2000 Count” column down the list to # 10, this is *Tellina modesta* (organism number 67, rank number 66). All 97 organisms below this rank were observed in fewer than 10 quadrats or cores over the entire length of Puget Sound. Continuing down the “2000 Count” column to # 117, this is Alaria sp. All 47 organisms below this ranking were not observed in both years, and 91% were only seen in 1999. Since they occur below the rank of 117 and were not observed in both years, they do not tell us anything about the condition of the pebble beach habitats. Based on the two years of sampling, we have no better than a 50% chance of finding these organisms on any given year. These chance occurrences or observations do little to increase the power of the dataset for change detection. However, they are useful in terms of monitoring the diversity of the habitat. But this diversity cannot be used to monitor for change since it is unlikely that even the 28% change that this represents from 1999 to 2000 is ecologically meaningful.

While Part 2 of this report addresses the use of taxonomic resolution in terms of applying the hierarchical taxonomic classification to preserved invertebrate samples collected from core samples, this discussion and Table 1 introduce the use of “complexes” to group taxa observed in the field into categories representing morphological similarity. The use of complexes speeds the field identification considerably and in most cases little information is lost while statistical rigor is enhanced. This is useful for taxa such as hermit crabs, red crusts, worm tubes and others that are difficult to rapidly identify in the field, or taxa that occur in very low numbers so that individual species become too infrequent to be statistically useful for comparisons. Species of *Pagurus* are not difficult to tell apart except that one has to wait for the crab to come out of its shell to make the identification. With the hundreds of hermit crabs found in the field, this would take too much time. Unless there is a specific need to make the species level identification on a *Pagurus*, a complex of *Pagurus* or even “hermit crabs” will do just as well statistically (since the number of observations is high). Red crusts and filamentous diatoms are other example of complexes that are frequently seen but are too difficult to identify to species in the field. Nereids are generally infrequent, but by grouping them into a complex their numbers are high enough to use as a monitoring signal. We have been using complexes (inadvertently) for our field identifications since this project started in 1997 and recommend that the field protocol continue using generally the same taxonomic categories as listed in Table 1 for the quadrat samples (see Part 2).

As we have seen in the analyses, the large number of species in the database does not add much to our ability to detect a change in the pebble beach communities over space or over time. However, these data are interesting in terms of monitoring the diversity of these communities. With that result identified, we recommend that sampling be conducted at a lower level of resolution every year, and that higher taxonomic resolution sampling be conducted periodically to track changes in diversity over time. At a minimum, the same sites sampled in 2000 should be sampled again in 2001. This will be suitable if the question of interest is among beach variation, and within Puget Sound variation. What cannot be addressed with this design is within bay, or within cell variation. To address within cell variation, all the sample sites from 1999 (the 3 x 3 x 4 design) in the Central Basin would need to be sampled. In addition we would have to find 6 more sites in Budd, Case, and Carr Inlets to match the statistical design. What may be more interesting is to sample physically similar sites on the west side of the Central Basin at the same latitude as the sample sites on the east side. Then we have along and across axis trends to analyze over time. The higher taxonomic resolution sampling should be done periodically, but as noted earlier, there was a 28% decrease in richness between 1999 and 2000 over the same sample sites, so diversity may not be a good indicator of change since many variables come into play when many different, but individually infrequent, species are collected and identified.

Part 2: Recommendations for Future Sampling

Site Recommendations

We recommend, for continuity, that the sites sampled in 2001 with the higher taxonomic resolution include all of the sites sampled in Summer 2000, as listed in Table 2. These include at least 9 beaches in South Sound and 12 beaches in Central Sound, one set of 3 beaches in each cell. We recommend that all surface quadrat sampling ("high" and "low" resolution) be done using the same taxonomic categories for year to year consistency. The "low resolution" sampling will thus consist of sites whose infauna (from core samples) are identified only to higher taxonomic categories (see below). If funding permits, identifying infauna from the 2001 samples to the species level for most or all sites will allow a good time series (1999 to 2001) for temporal analyses; thereafter, high-resolution sampling frequency could be reduced (see below).

Taxonomic Resolution: Literature Review

There is now adequate justification in the literature and in analyses of Puget Sound data for us to recommend a concrete methodology for lower-taxonomic-resolution sampling of shoreline biota, when time, funds, or taxonomic expertise do not permit the full high-resolution sampling used in the past. A variety of recent studies have considered the taxonomic levels at which spatial patterns can be detected. Most literature has examined pollution effects, and has shown that analyses at the level of family or even order are as good at detecting trends as are species-level analyses, allowing substantial savings of time and taxonomic expertise (reviewed by Somerfield and Clarke 1995, Olsgard et al. 1997, Olsgard and Somerfield 2000). Most studies have been done along minimal environmental gradients, so that the major extrinsic factor affecting the biota has been the anthropogenic disturbance under study. Organismal patterns are presumed to be closely linked to abiotic conditions, such that differences in the environment (e.g., in pollution level) result in differences in the biota that can be seen even when species are aggregated. If the same inferences about patterns in nature can be drawn from both species- and higher-taxa information, then the latter has been termed "sufficient" (Ellis 1985), or the former even "redundant" (Ferraro and Cole 1992). Such data have been used to define pollution indicators that are whole families rather than species. In some circumstances this could be misleading since species within an aggregation have the capacity to function independently of each other, and might undergo compensatory changes in response to a physical or chemical stressor. For example, one species might increase while another in the same family decreased; in this case, the family-level aggregation would appear insensitive to that stress. But if most of the species within a higher taxonomic category respond similarly to a stress, then those higher categories will be good indicators (Frost et al. 1992).

Anthropogenic factors may overwhelm faunal differences that might otherwise be seen along geophysical gradients. Olsgard et al. (1997) found that environmental variables like depth, sediment grain size and sorting, and % silt did not correlate with the spatial biotic patterns seen, whereas various parameters relating to the pollution source (an oil drilling platform) did. In contrast, in the one similar study in an undisturbed (unpolluted) systems, James et al. (1995) assessed the ability of family-level analyses to detect the same spatial patterns seen at the species level. They found that differences among depth gradients in infaunal sand-habitat communities were detected just as well at the family level, using both multivariate and univariate analyses. Olsgard and Somerfield (2000) recently examined the ability of higher taxonomic units to detect patterns in polluted, slightly polluted, and unpolluted areas. In all areas, family-level analyses (both examining diversity, and using multivariate analyses) closely correlated with species-level analyses, i.e. there was high concordance among trends seen using the different taxonomic categories. In highly polluted areas, there was still high correlation between species-level patterns and those detected by order- and phylum-level analyses, but these correlations were weak or absent in unpolluted areas. Polychaetes, the most abundant organisms in these samples, followed these general patterns but did not completely drive them, i.e. when the role of polychaetes in the data was reduced by subsampling them, the same patterns held. In the unpolluted areas, physical gradients such as water currents and overall grain size appear to drive the patterns and generate diverse communities, and there is apparently enough "redundancy" in terms of species per family that spatial patterns still are visible at the family level.

In our basic study of linkages between organisms and geophysical features (Schoch and Dethier 1997, 1999, Dethier and Schoch 2000), we needed the high sensitivity of the species level to test with rigor whether differences in soft-sediment fauna exist along natural (and subtle) physical gradients. We have demonstrated such linkages at the species level, but it also appears that the family level is sufficient to see faunal differences with relatively subtle changes in physical factors. Analyses of our 1997 data from Carr Inlet (for mud, sand, and cobble) showed that aggregating species at the family level distinguishes among communities in different substrate types as well as does the species-level data; the different substrate types in Carr Inlet contain significantly different communities at the family level. This is not surprising, since families of organisms like the dominant polychaetes have different lifestyles and thus might be expected to separate out by habitat type. When similar analyses were done within one substrate type but comparing different oceanographic cells, i.e. large regions of Carr Inlet differing primarily in wave energy and salinity, spatial patterns at both the species- and family-level again were quite similar. For example for the mud, there was almost no overlap in either species or families between the two cells; as salinity and wave energy shift, not only species but also families shift as well. Spatial patterns are somewhat less clear for the sand and the cobble, but in each case, patterns seen at the species level are echoed fairly closely at the family level. Clearly cell-level shifts in geophysical features affect the sand and cobble fauna less strongly than the mud fauna, but this contrast shows up regardless of taxonomic aggregation. Within a cell, for the mud there are visible differences among segments in both species and families; this means that the fauna is shifting predictably (even at the family level) among beaches within a cell. In the other two substrate types there is much higher overlap among beaches in the organisms present, or greater homogeneity at the within-cell level.

Thus overall, our preliminary analyses and the published literature indicate that family-level data are effective at distinguishing spatial patterns that correlate with shifts in geophysical features such as wave energy, salinity, and substrate type. Given that there are few species in most families in this database, it is likely that families shift among beaches at least in part because the species shift among beaches. Thus for the fauna in a relatively undisturbed portion of Puget Sound's shorelines, both species and families are tied to environmental gradients, especially in terms of substrate types. In these systems, results suggest (along with the various pollution studies) that the family level can be sufficient to detect change caused by *either* natural or anthropogenic factors.

Taxonomic Resolution: Recommendations

Similar analyses of the detectability of spatial patterns at different taxonomic levels have not yet been attempted with the pebble-substrate data from our more recent sampling efforts. Examination of the taxonomic lists from this habitat, however, strongly suggest that family-level sampling will allow us to distinguish patterns, in large part because of the distribution of species among higher taxonomic categories. Figure 17 shows that the 222 species found in pebble beaches at MLLW in Puget Sound (not including unidentified organisms or taxa identified only at a high level, such as Phylum Nemertea) are distributed among only 15 phyla and 23 classes, but 116 families. This suggests that analyses at the Phylum or Class level would be unlikely to detect patterns (no resolution possible), but that the large number of families probably would. Figure 17 also illustrates the distribution of species among families. One polychaete family (Spionidae) contained 14 species (many rare), and one polychaete (Cirratulidae) and one clam (Tellinidae) family contained 7 each, but this within-family diversity is rare; the vast majority (85%) of families contained only 1 or 2 species. This implies that identifying organisms only to family level (in both the field and in preserved lab samples) will result in a relatively small loss of information.

Table 3 lists the taxa we recommend for "low resolution" sampling in low-shore pebble habitats, divided by epifauna and epiflora (quadrat sampling), and infauna (later lab identification). Most of the animal taxa constitute families, although in the many cases where we have found only one species per family (e.g. in the anemones and some of the molluscs) we simply list the genus, as providing a more recognizable name. In a few cases we recommend the use of a higher taxon, usually when distinguishing families (e.g. of flatworms, nemerteans, brittle stars) is difficult in either the field or lab. Appendix B lists all of the species found, and the recommended higher taxon that they belong to. The epiflora separate less effectively by family (almost every species of algae found is in its own family) and the empirical justification of dividing by family that exists for marine invertebrates is lacking for the seaweeds. We thus recommend instead using algal functional groups, which have good theoretical and practical justification (e.g., Littler and Littler 1980, Steneck and Dethier 1994, Underwood and Petraitis 1993, Hixon and Brostoff 1996) as ecologically meaningful groupings. The groups we recommend (Table 3) are somewhat more finely divided than standard algal functional groups; they represent an attempt to maintain some potentially significant ecological distinctions among taxa (e.g. Fucus vs. kelps, which both could be lumped into "leathery macrophytes" but which have different growth modes and lifespans) while still lumping species that are likely to be similar and are difficult to distinguish in the field.

The major benefit of being able to detect patterns (natural or anthropogenic) at higher taxonomic levels is the clear savings in time and taxonomic expertise needed. We did not do a quantitative comparison of costs of different analyses, but the cost of family level identification in another study (Ferraro and Cole 1995) was 55% less than species-level. This figure will clearly vary greatly with number of species per family, types of organisms present (in taxonomically straightforward vs. difficult families), and type of taxonomic expertise available. In our Puget Sound samples, much of the time and expense of processing samples has been in identifying polychaetes to species; identifying them to family is quite simple and rapid, and the process is relatively straightforward for a non-expert to learn. Another possible advantage of using higher taxonomic categories was suggested by Ferraro and Cole (1990): such groupings may dampen natural variability in faunal patterns, i.e. fluctuations in the abundances of individual species, thus increasing statistical power to assess small pollution impacts.

Another, more pessimistic reason to do family-level analyses is that in most cases we have little information on the life history and ecology of the species (especially the less common ones), so that we do not necessarily gain an improved ability to interpret patterns when we analyze to the species level (James et al. 1995). A practical solution in many cases may be to store samples long-term, in the expectation that future analyses could be done at a finer level of taxonomic resolution if we learn more about sensitivities of particular species.

If further studies prove family-level analyses to be useful in detecting change, this has significant implications for monitoring programs. Beaches of a given geophysical type can be predicted to contain certain families, at least in Puget Sound. If one can quantify 'normalcy' or health of the biota of a given beach at the family level, then additional effort that might have gone into species identifications could be used instead for improved spatial replication.

At this time, no studies have clearly identified the processes that enable taxonomic aggregations to “work” in terms of detecting spatial patterns, although a variety of theories are discussed in Olsgard et al. (1997) and Olsgard and Somerfield (2000). Because our communities are taxonomically diverse at the family level, it is probabilistic that similar patterns in space will be found at the family and species levels. Warwick (1988) suggested that “gradients in natural environmental variables, such as water depth and sediment granulometry, are more likely to influence the fauna by species replacement than by changes in proportions of major taxa”, but this does not appear to be the case in our data.

The major cost of analyses done at higher taxonomic levels is the potential loss of important information visible only at the species level. The importance of this depends on how similar ecologically are the species within an aggregate. Clarke and Warwick (1998) found that several species within taxa and functional groups (e.g., deposit-feeding polychaetes) appear to react in similar ways to environmental variability (polluted and unpolluted areas). In contrast, Rakocinski et al. (1997) found that species-level analyses were very useful for understanding community shifts relative to a contamination gradient in their system, because even within a group (e.g., capitellids) there were fine-scale differences in species relationships to contaminants. Our data suggest a similar meaningful separation of capitellid polychaetes among areas, and this may be group for which we want to continue to gather high-resolution data. Rakocinski et al. (1997) did note that “relationships were often qualitatively similar within a group,” suggesting a link between the scale of the gradient to be analyzed and the level of taxonomic resolution needed. Frost et al. (1992) note that while natural variability is likely to be higher at the species level than for taxonomic aggregates, the tradeoff is that abundances of species may be more sensitive indicators of stress. They suggest that effective indicators of stress may comprise intermediate levels of aggregation (e.g., genus or family rather than either species or order), which can provide the best combination of sensitivity and variability.

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Figure 1

This map of the South and Central Basins of Puget Sound shows the sites sampled for this study. Budd, Case, and Carr Inlets in the South Basin, and Redondo, Brace, Carkeek, and Possession in the Central Basin.

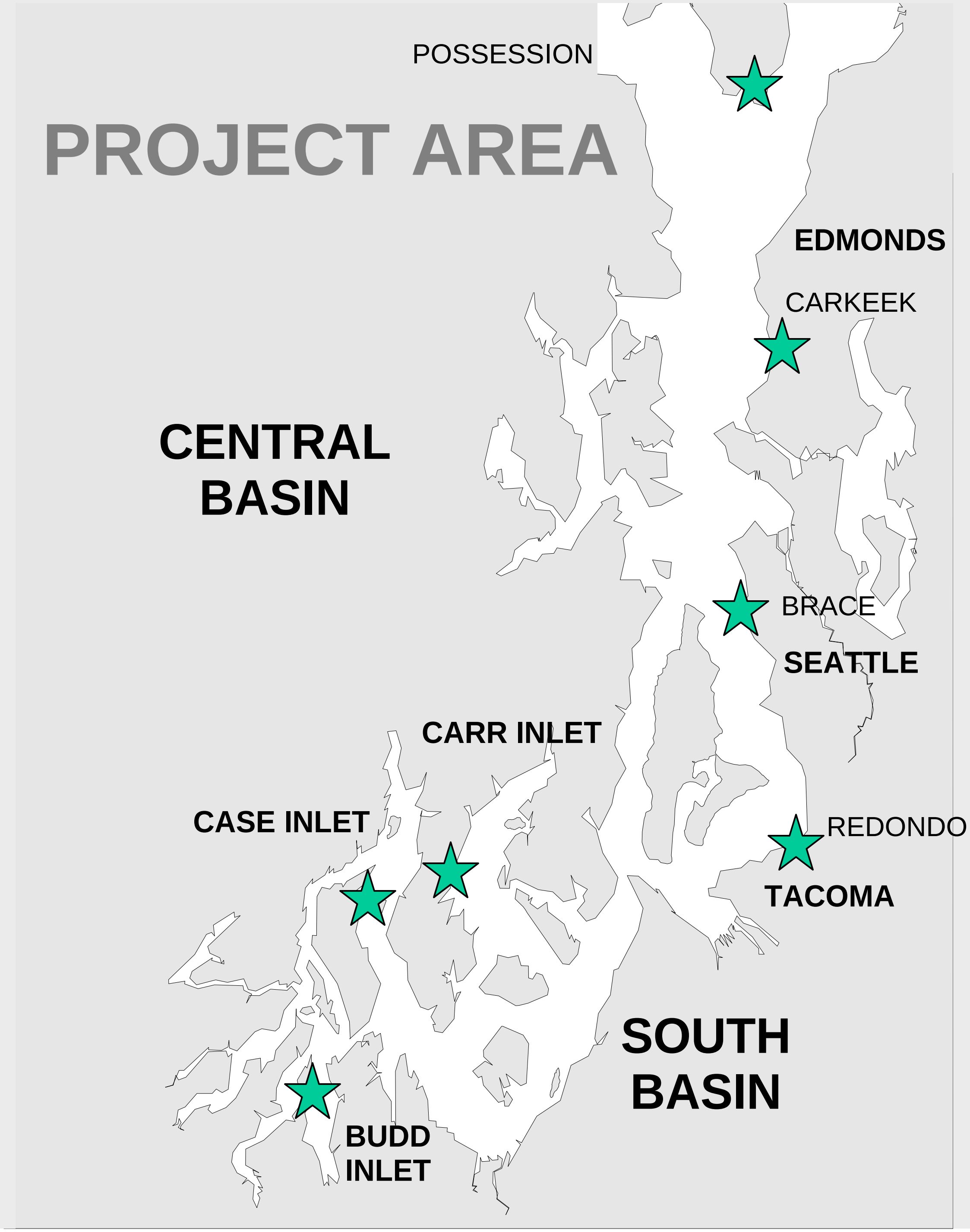
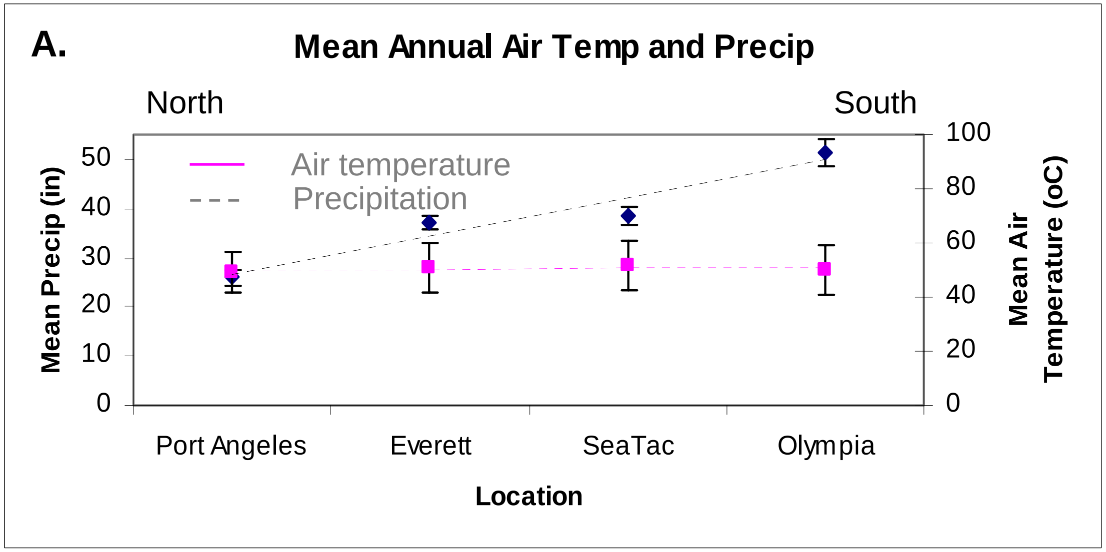


Figure 2

Figure A shows the annual air temperature and precipitation trends along the axis of Puget Sound. Error bars show one SD. The air temperature shows little variation, but the precipitation is approximately twice as high in Olympia as Port Angeles. Figure B shows the predicted variation in tide range along the axis of Puget Sound. The range is twice as high at Olympia as Port Angeles.



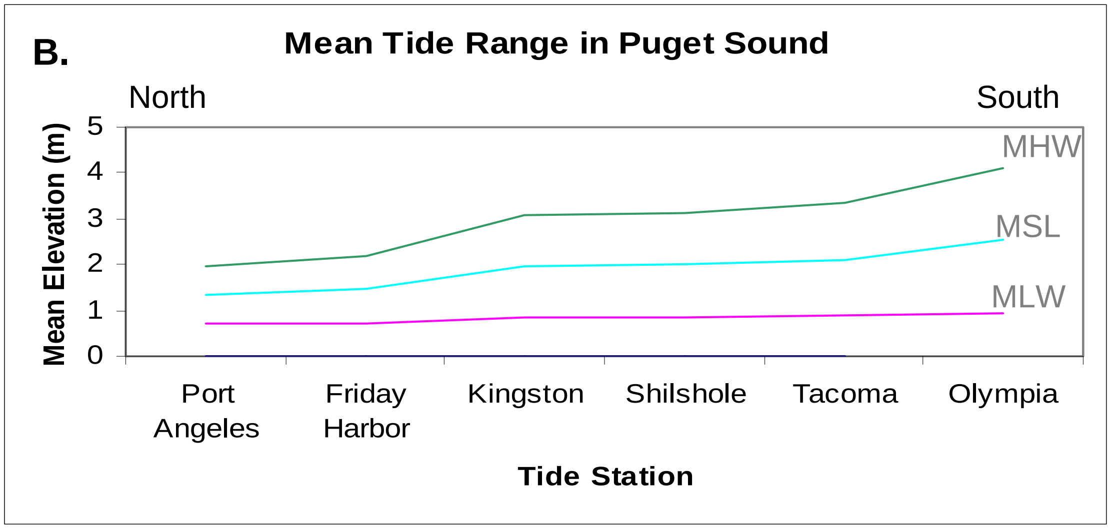


Figure 3

This figure shows the mean monthly air temperature along the axis of Puget Sound averaged from 1995 to 2000. Note that there is little difference among the measurement stations, they all exhibit the same general temperature ranges.

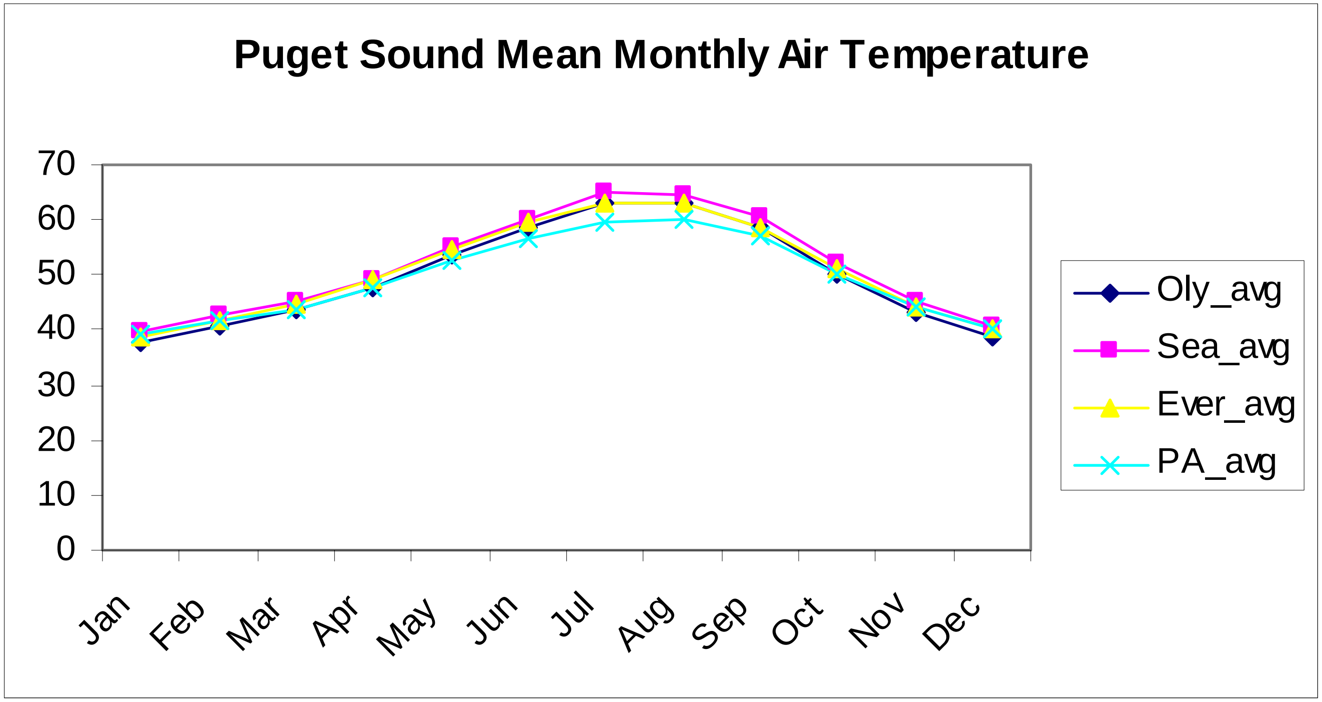


Figure 4

This map of the South and Central Basins of Puget Sound shows the sites sampled monthly by the Washington Department of Ecology as part of a water quality program (in red), and the Washington Department of Natural Resources transects sampled as part of this study

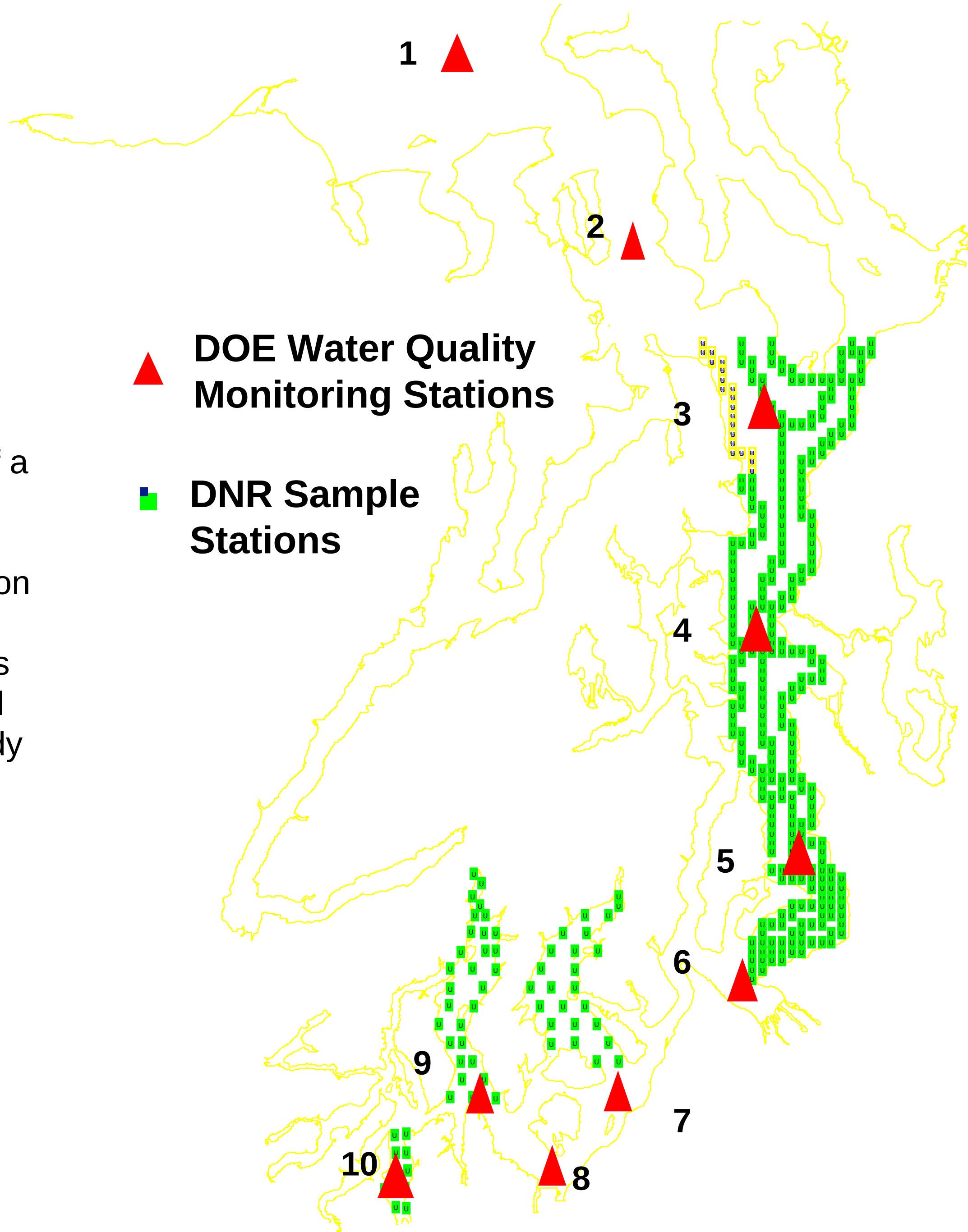


Figure 5

Figure A shows the mean annual sea surface temperature at the DOE sites at 2 m depth. Error bars show one SD. Note the positive trend in water temperature from north to south along the axis of Puget Sound. Figure B shows the water salinity which shows a negative trend along the axis.

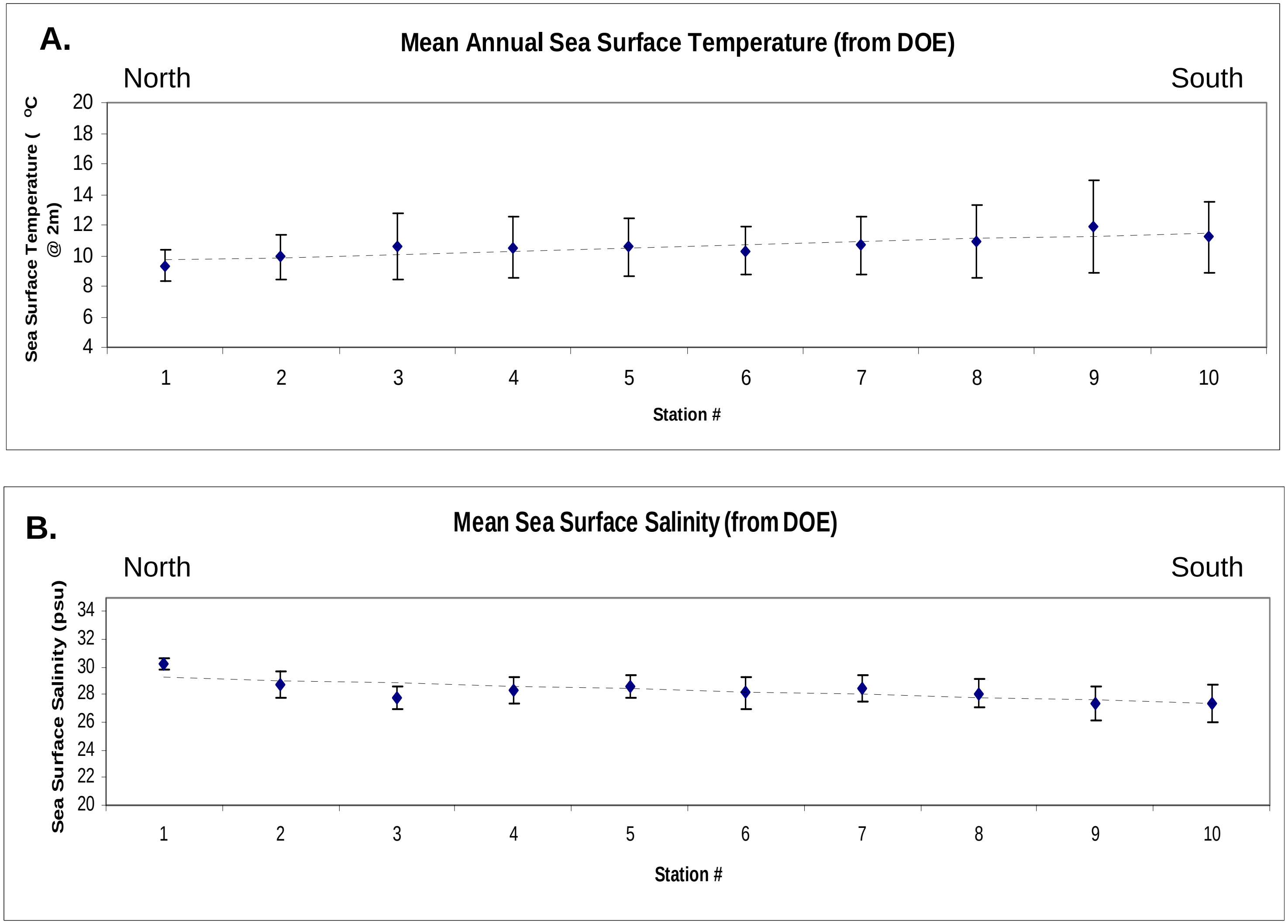
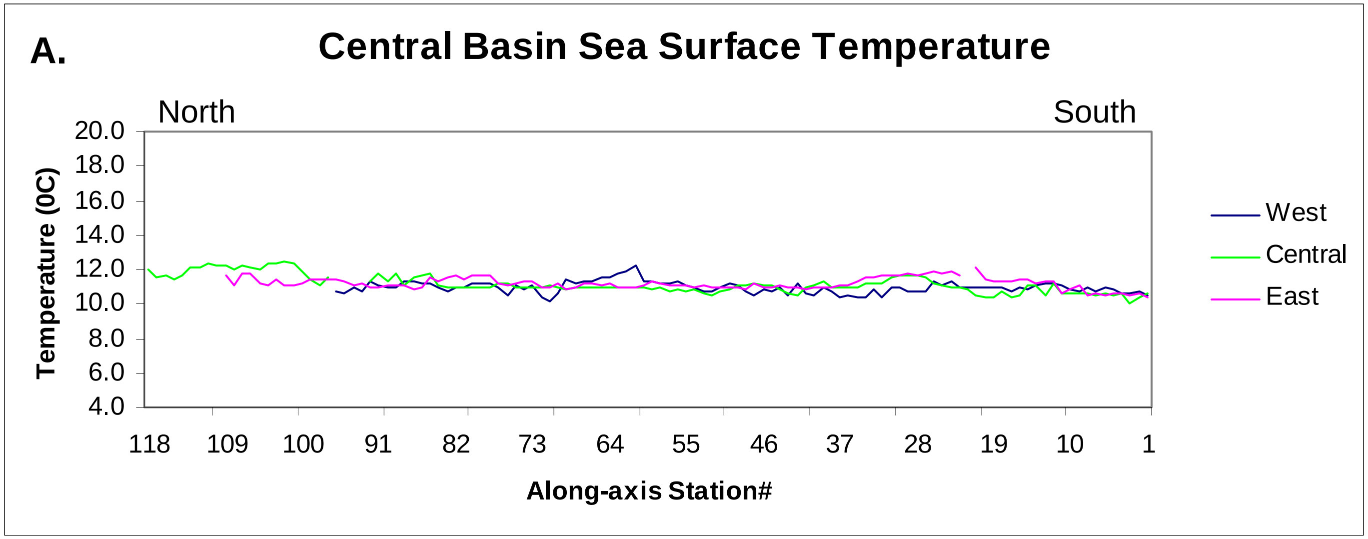


Figure 6

Figure A shows the results of the WDNR temperature survey along and across the axis of Puget Sound. There is approximately 2 degrees difference between the north and south ends of the transect. Figure B shows the salinity data. While there are the expected decreases in salinity in Possession Sound, Elliot Bay and Commencement Bay, there is also a slightly negative trend from north to south. Interestingly, these data show a marked across axis gradient with higher salinity water along the west side of the Sound.



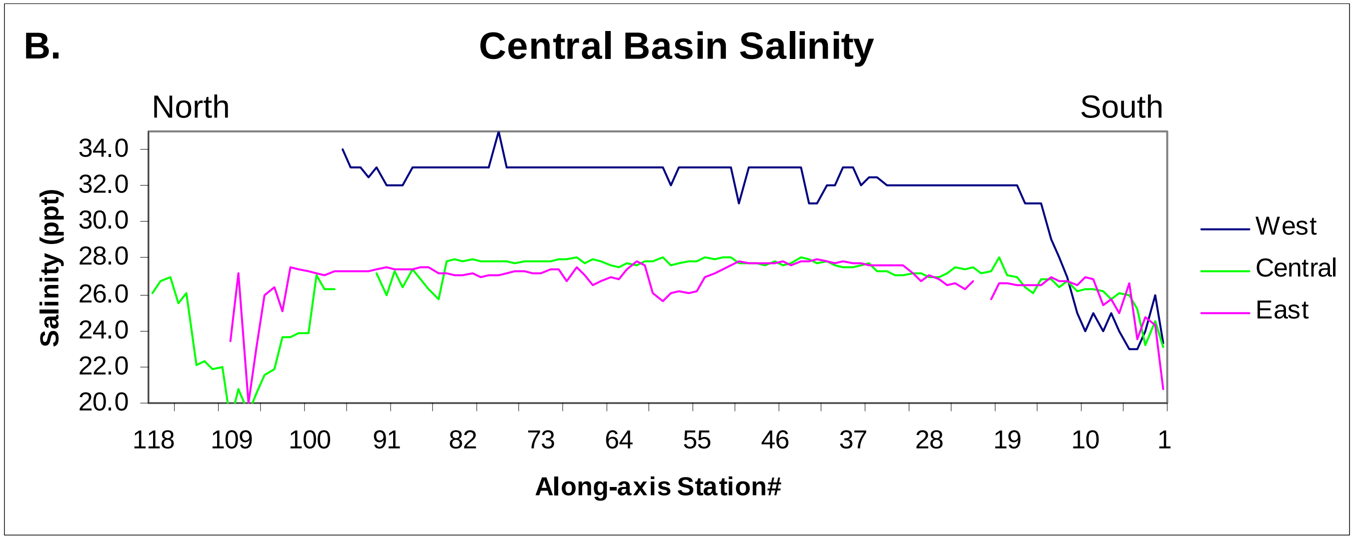
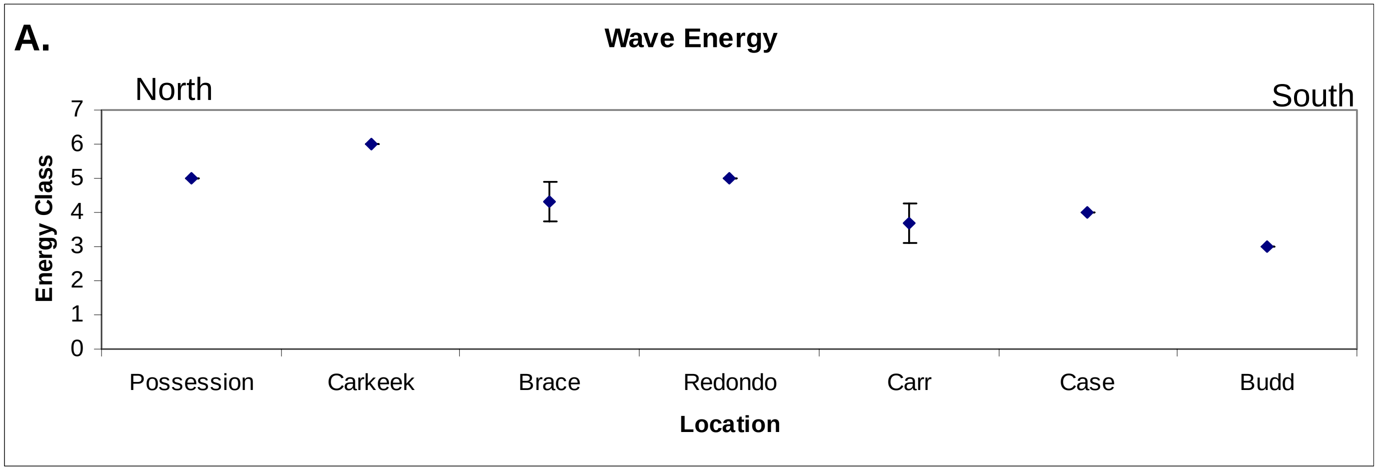


Figure 7

Figure A shows the calculated mean annual wave energy for the sample sites used in this study. Error bars show one SD. The northern sites have higher wave energy than the southern sites mostly as a function of wind velocity since the other attributes of the beaches were the same e.g. aspect, slope angle, etc. Figure B shows the substrate size distribution for the sampled beaches. There is a marked increase in sand from north to south and a decrease in coarser particles.



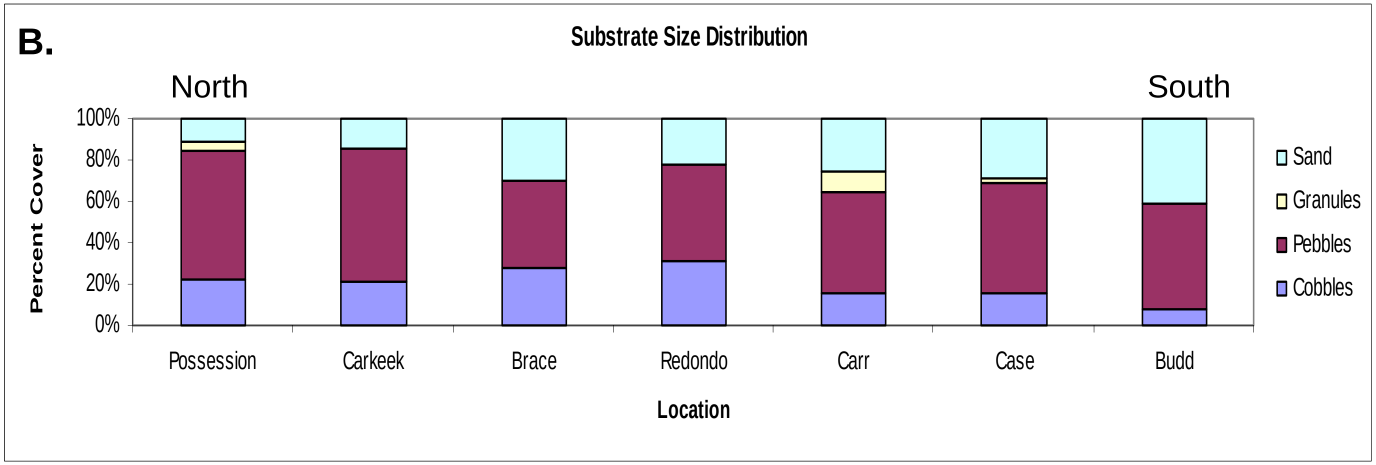
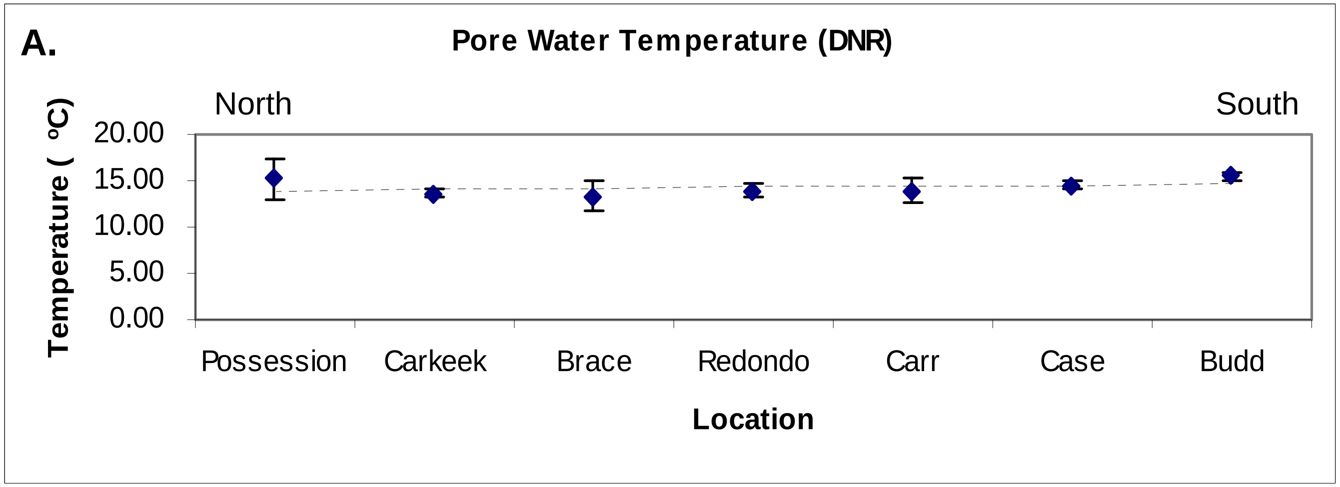


Figure 8

Figure A shows the pore water temperature for the sampled beaches. Figure B shows the pore water salinity. Error bars on both figures are at one SD. There is little discernible trend in these data. Salinity varies considerably within and among sites and temperature stays relatively constant.



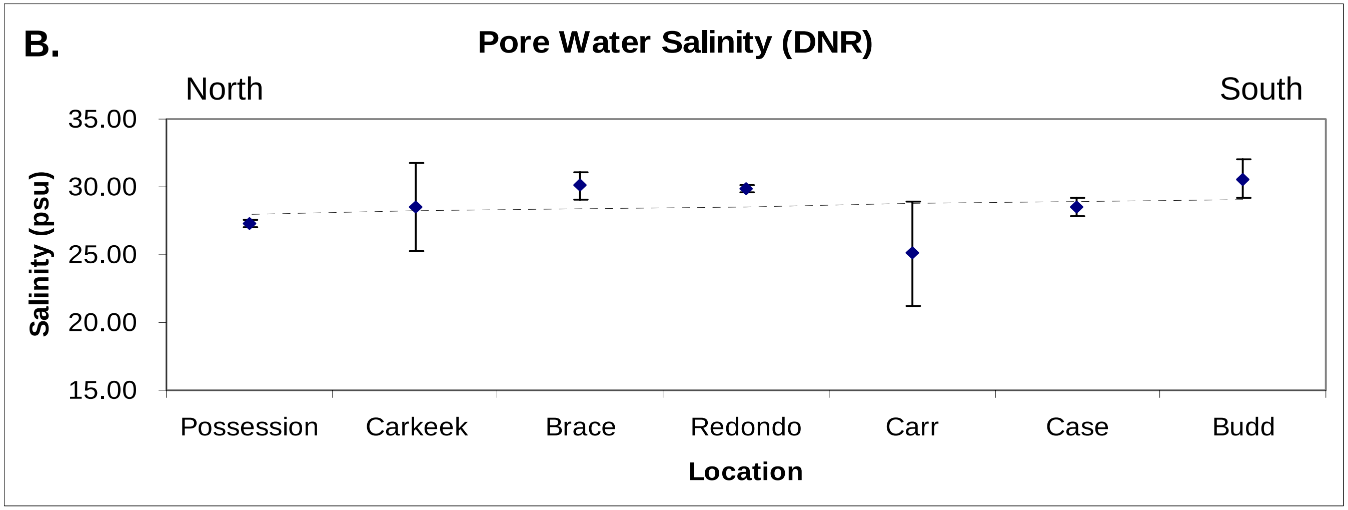


Figure 9

This figure shows the along axis richness of the samples collected from the three beaches at each locations. The richness data has been partitioned to show the relative contributions from quadrats and cores. There is a negative trend in richness from north to south manifested in both quadrat and core samples. Interestingly, the contribution from cores increases from north to south, but this may be a function of the increasing amount of fine substrate particles.

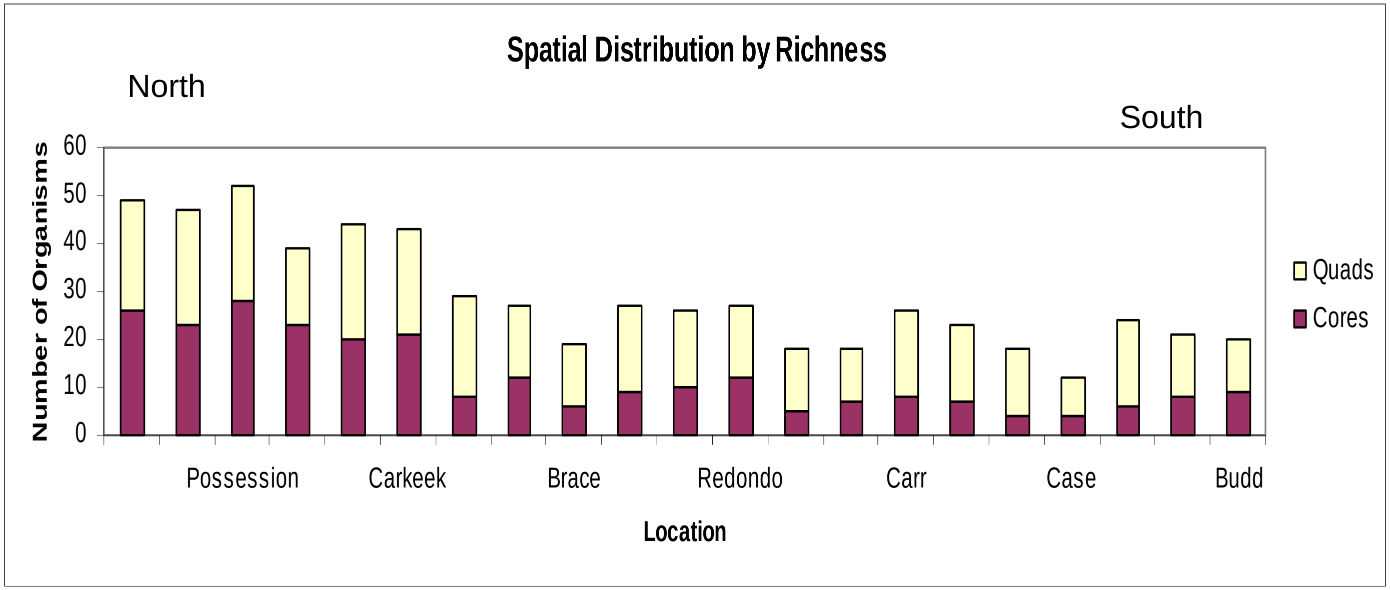


Figure 10

Figure A shows the trophic distribution for the organisms found in 2000. The Y axis represents the number of occurrences in all the quadrats and cores sampled. Figure B shows the number of occurrences for each phyla.

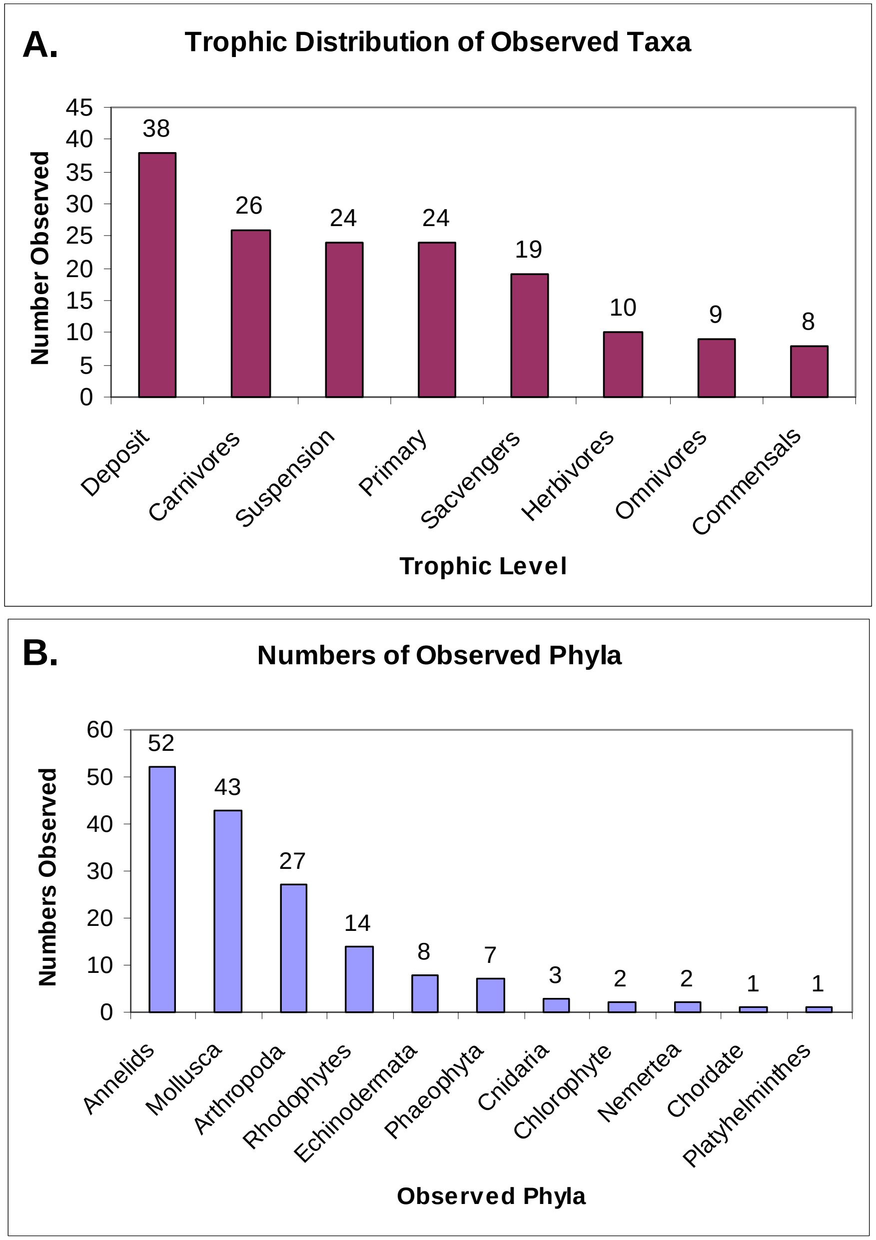


Figure 11

The number of organisms observed at each sample site is shown here partitioned by trophic level. There is a discernible negative trend from norht to south in carnivores, algae, herbivores, and deposit feeders.

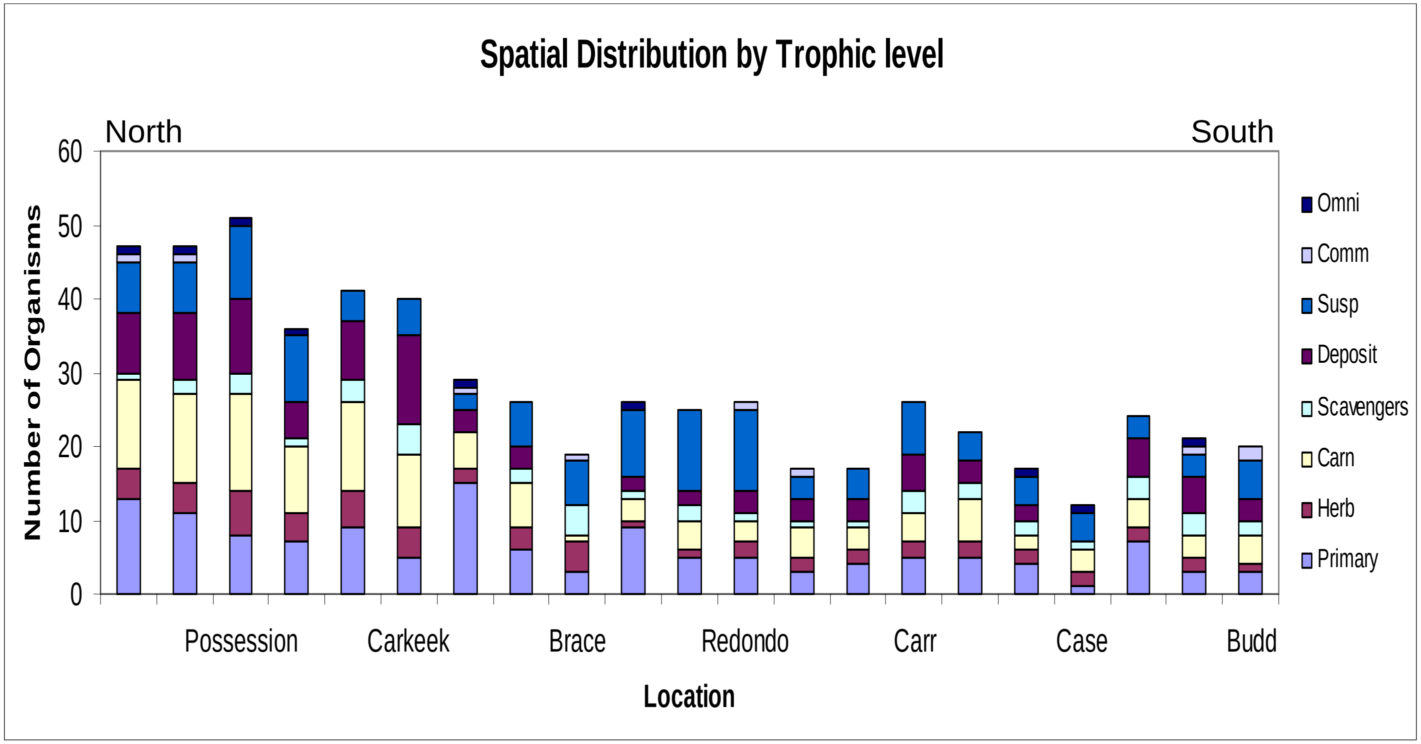


Figure 12

This figure shows the ordination plot for the communities sampled in both 1999 and 2000. Each data point represents a quadrat/core sample. Note that quadrat/cores for most beaches are grouped close together suggesting a community with high fidelity to specific beach habitats. Solid symbols are for samples collected in 2000, and the open symbols are for 1999 samples.

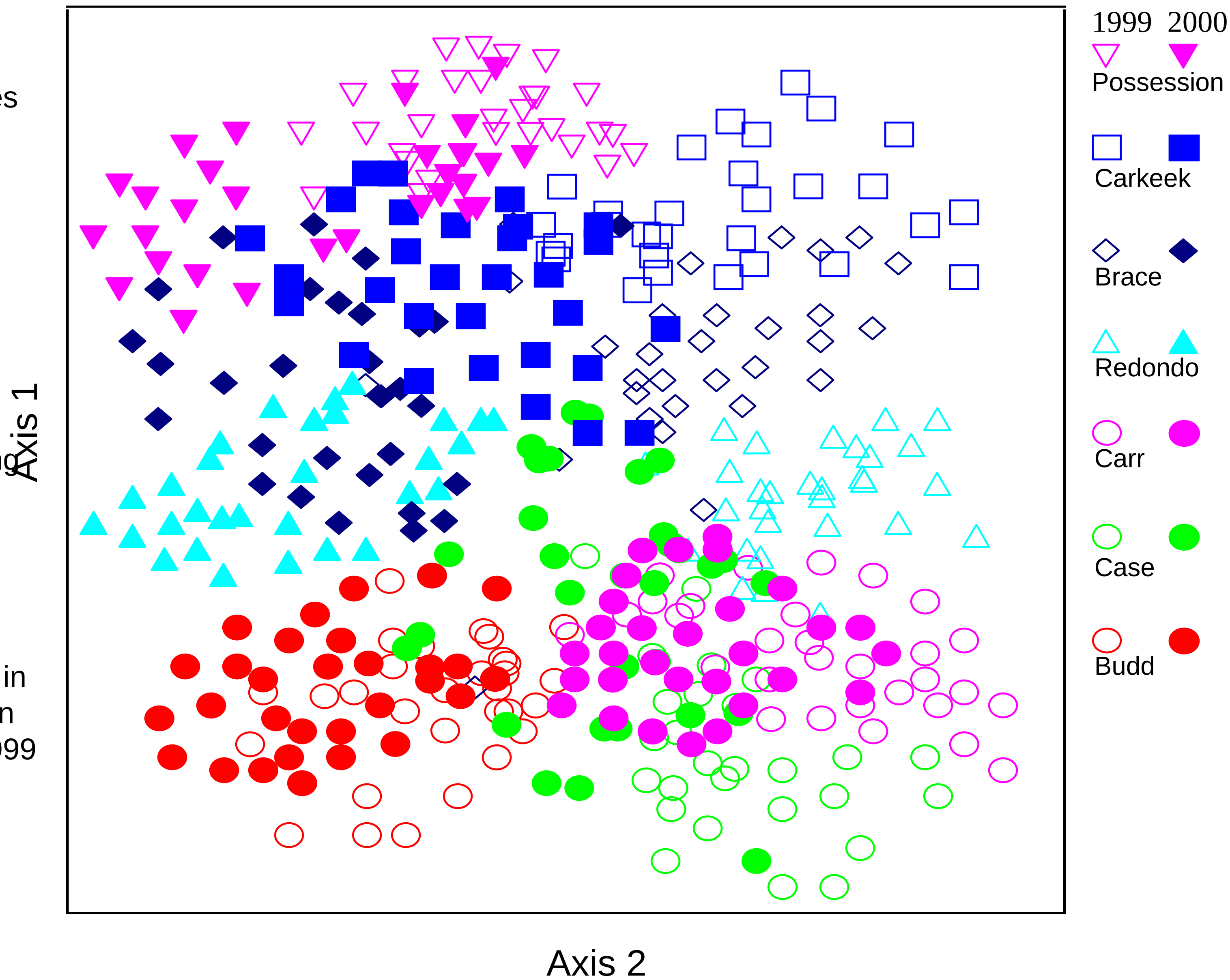


Figure 13

This figure shows the same ordination plot as Figure 12, but polygons have been drawn around the sample points from each site to show the geographic distribution of the communities. The plot shows that samples from the northern sites are towards the top of the plot, while samples from the south are towards the bottom of the plot. Samples from 1999 are towards the right and samples from 2000 are towards the left.

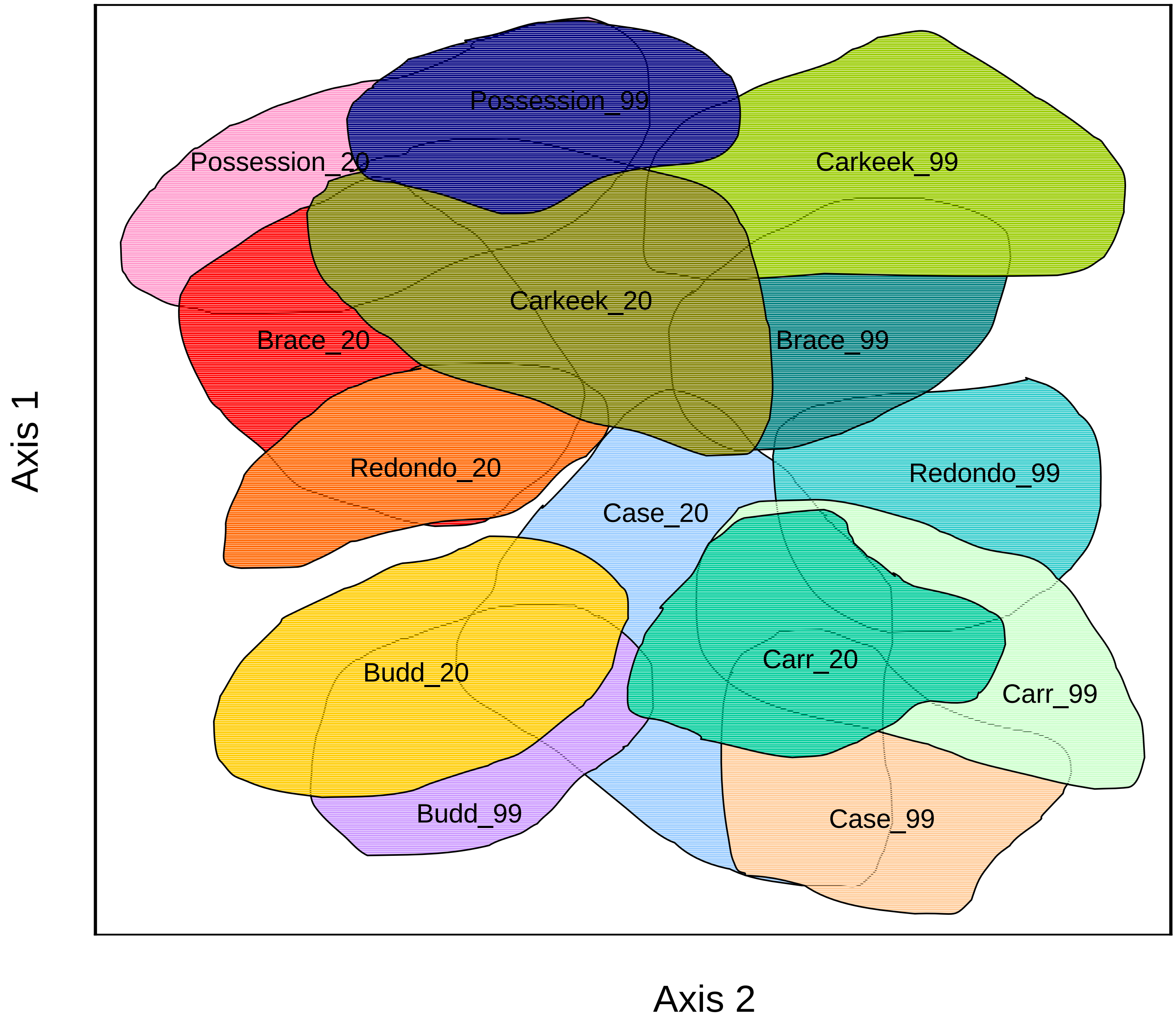


Figure 14

This figure shows the same ordination plot as Figure 13, but here with the results of the TWINSPAN analysis for the first major division of communities. Note that Redondo 1999 is in the lower group, and Redondo 2000 is in the upper group. This suggests that the spatial division is not related to any geographic feature of Puget Sound, and that geographic shifts occur over time based on other features of the habitat and/or species behavior.

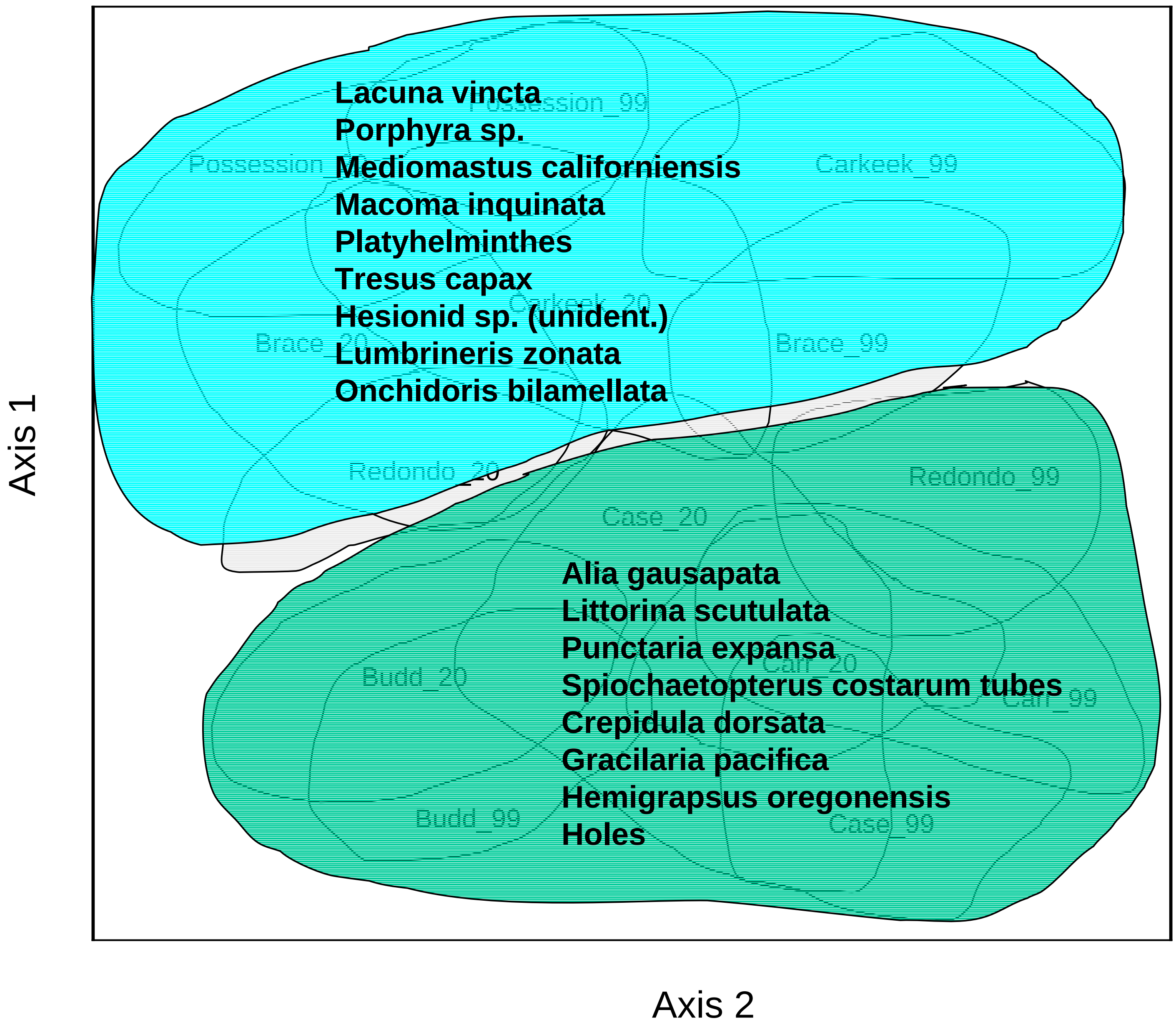


Figure 15

This figure shows the same ordination but with the results of the second and third TWINSPAN divisions. The upper group from Figure 14 has been divided roughly into the samples collected in 1999 (tan), and the samples collected in 2000 (red). The lower group was divided into samples from Budd Inlet (yellow) for both 1999 and 2000, and for Case, Carr and Redondo 1999 (purple).

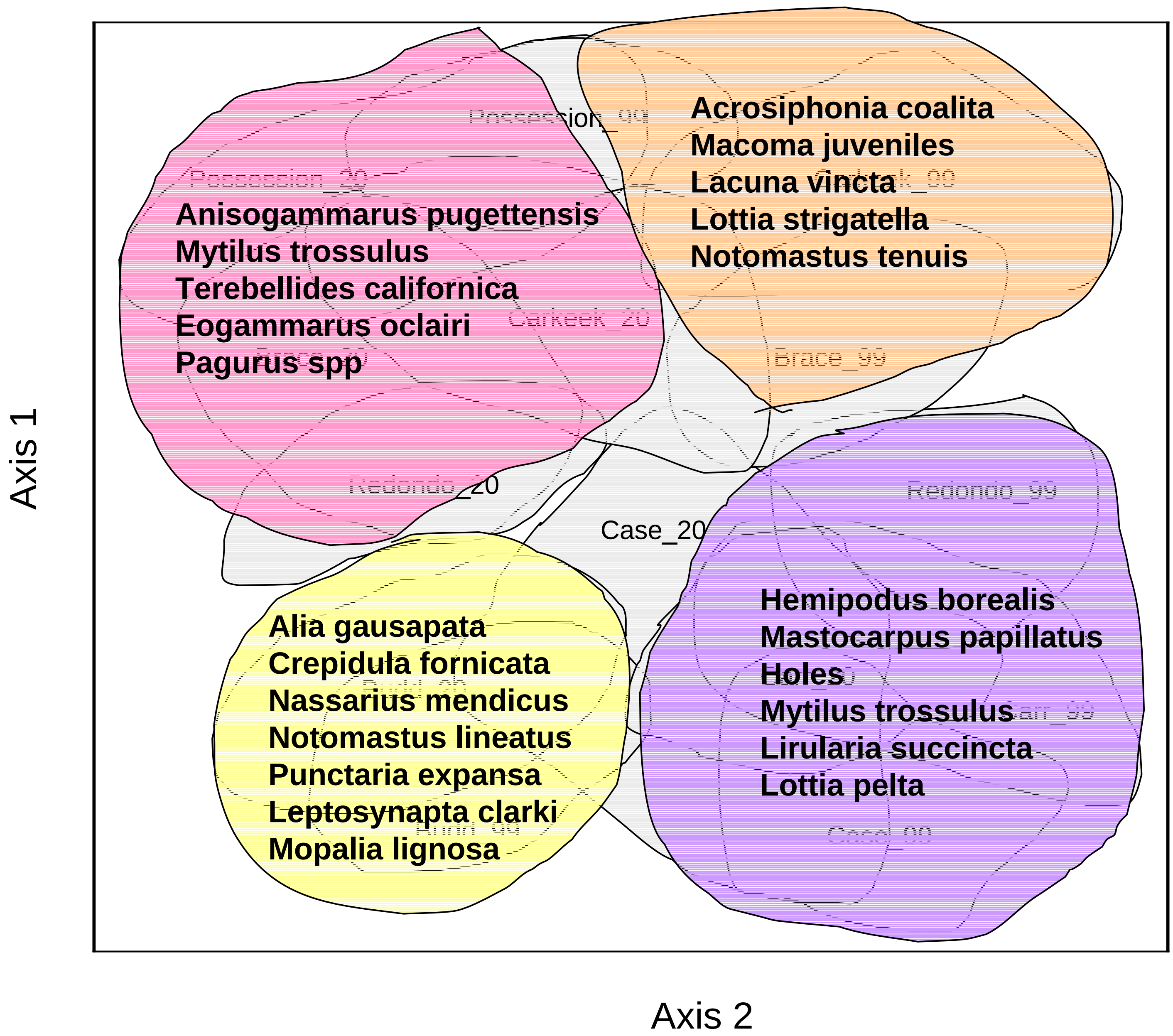


Figure 16

This figure shows the same ordination plot but with the correlated physical attributes shown as vectors on the geographic polygons. The length and direction of the vector indicates the strength of the correlation to the plotted points (polygons). This figure shows that the northern communities are correlated to higher wave energy and larger substrate size than the southern communities. Also the southern communities are correlated to more sand, higher precipitation, and water temperature.

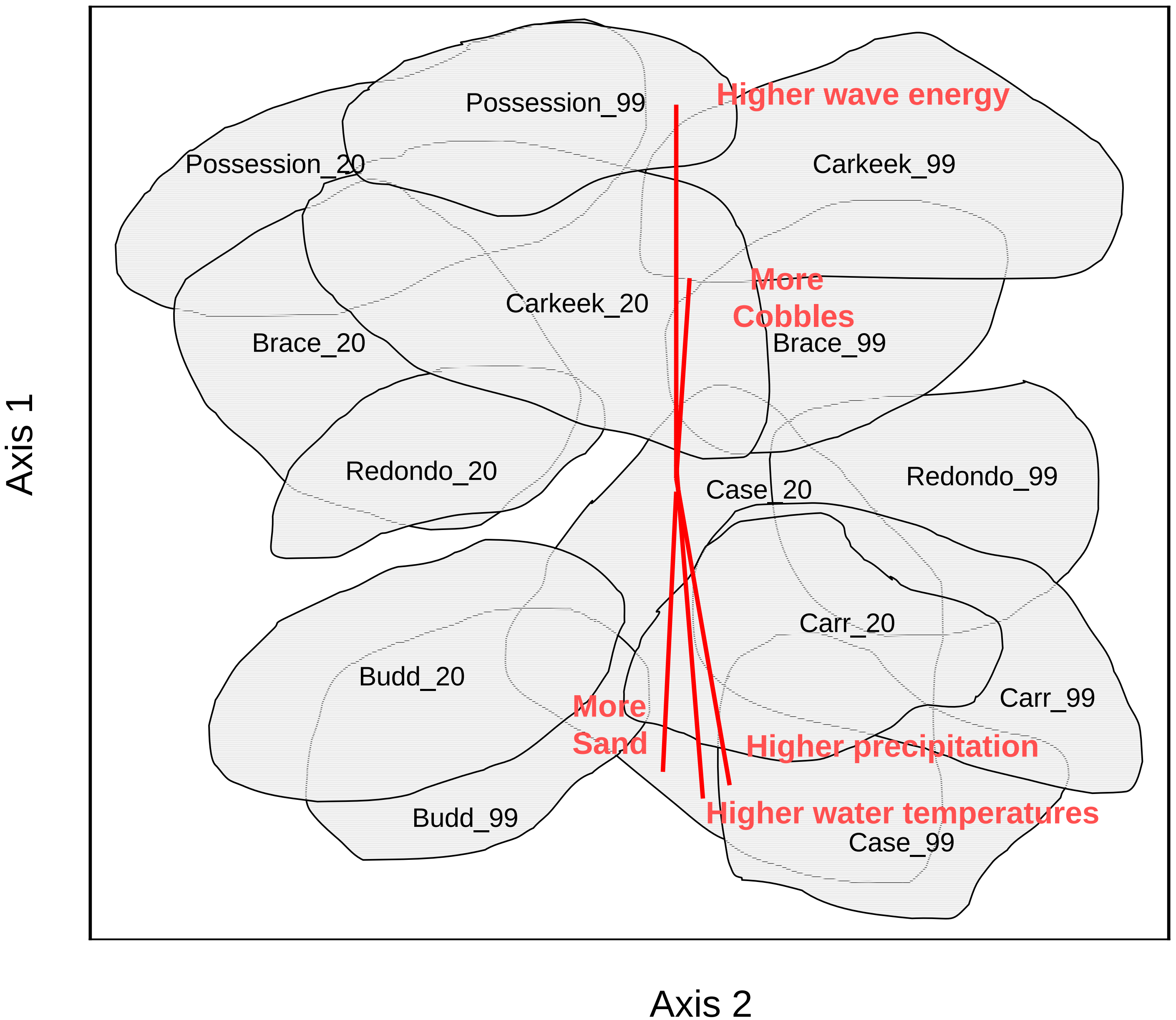


Table 1. The organisms found in a total of 210 quadrats and cores over 21 sites in year 2000. The organisms are listed by count (out of a possible 210), and by rank for each sample year. If an organism was present in both sample years, or in either year, then an "X" is shown in columns labelled Both, 2000, or 1999. The phylum, family, and trophihc level for each organism is also listed.

#	2000 Organism Rank	2000 Count	2000 Rank	1999 Count	1999 Rank	Both	2000	1999	PHYLUM	FAMILY	TROPHIC
1	Ulvoid Complex	209	1	202	2	X			Chlorophyta		Prim
2	Balanus glandula	207	2	208	1	X			Arthropoda	Balanidae	Susp
3	Red Crust Complex	189	3	187	3	X			Rhodophyta		Prim
4	Lottia pelta	170	4	176	4	X			Mollusca	Lottiidae	Herb
5	Pagurus Complex	155	5	128	8	X			Arthropoda	Paguridae	Scav
6	Mytilus trossulus	145	6	148	5	X			Mollusca	Mytilidae	Susp
7	Mastocarpus papillatus	128	7	112	11	X			Rhodophyta	Petrocelidaceae	Prim
8	Notomastus tenuis	127	8	133	6	X			Annelida	Capitellidae	Dep
9	Nucella lamellosa	120	9	105	14	X			Mollusca	Nucellidae	Carn
10	Porphyra Complex	118	10	118	9	X			Rhodophyta	Bangiaceae	Prim
11	Flatworm Complex	102	11	58	23	X			Platyhelminthes		Carn
12	Acrosiphonia coalita	94	12	133	7	X			Chlorophyta	Acrosiphoniaceae	Prim
13	Hemigrapsus oregonensis	92	13	113	10	X			Arthropoda	Grapsidae	Scav
14	Polynoid Complex	85	14	70	20	X			Annelida	Polynoidae	Carn
15	Onchidoris bilamellata	81	15	46	28	X			Mollusca	Onchidorididae	Carn
16	Punctaria expansa	78	16	106	13	X			Phaeophyta	Punctariaceae	Prim
17	Hemipodus borealis	76	17	105	15	X			Annelida	Glyceridae	Carn
18	Scytosiphon lomentaria	73	18	108	12	X			Phaeophyta	Scytosiphonaceae	Prim
19	Mopalia lignosa	73	19	77	19	X			Mollusca	Mopaliidae	Herb
20	Polysiphonia Complex	70	20	39	32	X			Rhodophyta	Rhodomelaceae	Prim
21	Lacuna vincta	68	21	88	16	X			Mollusca	Lacunidae	Herb
22	Amphipholis squamata	66	22	24	44	X			Echinodermata	Amphiuridae	Scav
23	Holes Complex	64	23	83	17	X					Misc
24	Macoma inquinata	62	24	33	33	X			Mollusca	Tellinidae	Dep
25	Sabellid Tube Complex	61	25	79	18	X			Annelida	Sabellidae	Susp
26	Nemertean Complex	61	26	40	30	X			Nemertea		Carn
27	Saxidomus giganteus juv.	57	27	45	29	X			Mollusca	Veneridae	Susp
28	Gracilaria pacifica	56	28	16	55	X			Rhodophyta	Gracilariaceae	Prim

Table 1. continued

#	2000 Organism Rank	2000 Count	2000 Rank	1999 Count	1999 Rank	Both	2000	1999	PHYLUM	FAMILY	TROPHIC
29	Alia gausapata	50	29	48	27	X			Mollusca	Columbellidae	Carn
30	Macoma inquinata juveniles	49	30	70	21	X			Mollusca	Tellinidae	Dep
31	Filamentous Diatoms	48	31	0			X				
32	Mediomastus californiensis	46	32	52	24	X			Annelida	Capitellidae	Dep
33	Terebellid Tube Complex	41	33	0			X		Annelida	Terebellidae	Dep
34	Lirularia succincta	40	34	67	22	X			Mollusca	Trochidae	Herb
35	Eogammarus oclairi	38	35	8	73	X			Arthropoda	Anisogammaridae	Scav
36	Crepidula dorsata	37	36	31	36	X			Mollusca	Calyptraeidae	Susp
37	Protothaca staminea	36	37	26	40	X			Mollusca	Veneridae	Susp
38	Lottia strigatella	34	38	50	26	X			Mollusca	Lottiidae	Herb
39	Tresus capax	33	39	13	61	X			Mollusca	Mactridae	Susp
40	Exosphaeroma inornata	32	40	26	41	X			Arthropoda	Flabellifera	Scav
41	Hermissenda crassicornis	30	41	19	49	X			Mollusca	Facelinidae	Carn
42	Lumbrineris zonata	27	42	22	46	X			Annelida	Lumbrineridae	Omni
43	Mazzaella heterocarpa	27	43	3	97	X			Rhodophyta	Gigartinaceae	Prim
44	Siphons	26	44	1	117	X					
45	Notomastus lineatus	25	45	25	43	X			Annelida	Capitellidae	Dep
46	Lophopanopeus bellus bellus	25	46	23	45	X			Arthropoda	Xanthidae	Carn
47	Semibalanus cariosus	24	47	32	35	X			Arthropoda	Archaeobalanidae	Susp
48	Monocorophium acherusicum	24	48	0			X		Arthropoda	Corophiidae	Scav
49	Spio filicornis	21	49	17	54	X			Annelida	Spionidae	Dep/Susp
50	Hesionid Complex	20	50	33	34	X			Annelida	Hesionidae	Omni
51	Capitella capitata	18	51	4	85	X			Annelida	Capitellidae	Dep
52	Cirratulus cingulatus	17	52	19	50	X			Annelida	Cirratulidae	Dep
53	Glycinde picta	16	53	16	56	X			Annelida	Goniadidae	Carn
54	Laminaria saccharina	16	54	4	86	X			Phaeophyta	Laminariaceae	Prim
55	Leptosynapta clarki	15	55	31	37	X			Echinodermata	Synaptidae	Dep
56	Armandia brevis	14	56	31	38	X			Annelida	Opheliidae	Dep
57	Crepidula fornicata	14	57	26	42	X			Mollusca	Calyptraeidae	Susp
58	Anthopleura elegantissima	14	58	18	51	X			Cnidaria	Actiniidae	Carn
59	Protothaca staminea juv.	14	59	18	52	X			Mollusca	Veneridae	Susp
60	Saxidomus giganteus	14	60	13	62	X			Mollusca	Veneridae	Susp
61	Nereis zonata	14	61	0			X		Annelida	Nereidae	Omni

Table 1. continued

#	2000 Organism Rank	2000 Count	2000 Rank	1999 Count	1999 Rank	Both	2000	1999	PHYLUM	FAMILY	TROPHIC
62	Tresus capax juveniles	13	62	52	25	X			Mollusca	Mactridae	Susp
63	Harmothoe imbricata	13	63	10	68	X			Annelida	Polynoidae	Carn
64	Pododesmus cepio	12	64	20	48	X			Mollusca	Anomiidae	Susp
65	Gnorimosphaeroma oregonense	12	65	14	59	X			Arthropoda	Sphaeromatidae	Scav
66	Tellina modesta	10	66	8	74	X			Mollusca	Tellinidae	Dep
67	Phoronopsis harmeri	9	67	18	53	X			Phoronida	Phoronidae	Susp
68	Nereis procera	9	68	15	58	X			Annelida	Nereidae	Omni
69	Gunnel Complex	9	69	12	64	X			Chordata		Carn
70	Cancer Crab Complex	9	70	3	98	X			Arthropoda	Cancridea	Carn
71	Leitoscoloplos pugettensis	8	71	13	63	X			Annelida	Orbiniidae	Dep
72	Nassarius mendicus	7	72	28	39	X			Mollusca	Nassariidae	Scav
73	Idotea sp.	7	73	9	69	X			Arthropoda	Idoteidae	Herb
74	Prionitis Complex	7	74	9	70	X			Rhodophyta	Halymeniaceae	Prim
75	Hiatella arctica	7	75	0			X		Mollusca	Hiatellidae	Susp
76	Nereid Complex	6	76	4	87	X			Annelida	Nereidae	Omni
77	Pectinaria granulata	6	77	4	88	X			Annelida	Pectinariidae	Dep
78	Pinnotherid sp. (unident.)	6	78	2	107	X			Arthropoda	Pinnotheridae	Comm
79	Panomya chrysis	6	79	0			X		Mollusca	Hiatellidae	
80	Fucus gardneri	6	80	0			X		Phaeophyta	Fucaceae	Prim
81	Nephtys Complex	5	81	4	89	X			Annelida	Nephtyidae	Carn
82	Owenia fusiformis	4	82	9	71	X			Annelida	Oweniidae	Dep
83	Euclymene sp.A	4	83	7	77	X			Annelida	Maldanidae	Dep
84	Odonthalia floccosa	4	84	7	78	X			Rhodophyta	Rhodomelaceae	Prim
85	Cirriformia sp.A	4	85	2	108	X			Annelida	Cirratulidae	Dep
86	Platynereis bicanaliculata	4	86	1	118	X			Annelida	Nereidae	Omni
87	Edwardsia sipunculoides	4	87	1	119	X			Cnidaria	Edwardsiidae	Susp
88	Euclymene sp.B (cf. zonalis)	3	88	4	90	X			Annelida	Maldanidae	Dep
89	Tectura scutum	3	89	3	99	X			Mollusca	Lottiidae	Herb
90	Odostomia sp. (unident.)	3	90	2	109	X			Mollusca	Pyramidellidae	Carn
91	Malmgreniella nigralba	3	91	1	120	X			Annelida	Polynoidae	Comm
92	Lucina tenuisculpta	3	92	1	121	X			Mollusca	Lucinidae	Susp
93	Tanaid.C	3	93	0			X				
94	Nephtys caecoides	2	94	7	79	X			Annelida	Nephtyidae	Carn

Table 1. continued

#	2000 Organism Rank	2000 Count	2000 Rank	1999 Count	1999 Rank	Both	2000	1999	PHYLUM	FAMILY	TROPHIC
95	Glycera americana	2	95	6	83	X			Annelida	Glyceridae	Carn
96	Cirratulus multioculata(?)	2	96	5	84	X			Annelida	Cirratulidae	Dep
97	Axiothella rubrocincta	2	97	3	100	X			Annelida	Maldanidae	Dep
98	Aphelochaeta multifilis	2	98	2	110	X			Annelida	Cirratulidae	Dep
99	Dendraster excentricus	2	99	2	111	X			Echinodermata	Dendrasteridae	Susp
100	Macoma nasuta	2	100	2	112	X			Mollusca	Tellinidae	Dep
101	Nephtys ferruginea	2	101	1	122	X			Annelida	Nephtyidae	Carn
102	Haminoea vesicula	2	102	0			X		Mollusca	Atyidae	Herb
103	Pseudopythina rugifera	2	103	0			X		Mollusca	Montacutidae	Comm
104	Stronglyocentrotus droebachien	1	104	21	47	X			Echinodermata	Strongylocentrotida	Herb
105	Neotrypaea californiensis	1	105	11	65	X			Arthropoda	Callianassidae	Dep
106	Metridium senile	1	106	8	75	X			Cnidaria	Metridiidae	Susp
107	Leptasterias hexactis	1	107	7	80	X			Echinodermata	Asteriidae	Carn
108	Clinocardium nuttallii	1	108	7	81	X			Mollusca	Cardiidae	Susp
109	Sarcodiotheca sp. (unid.)	1	109	4	91	X			Rhodophyta	Solieriaceae	Prim
110	Pherusa plumosa	1	110	3	101	X			Annelida	Flabelligeridae	Dep
111	Micropodarke dubia	1	111	1	123	X			Annelida	Hesionidae	Omni
112	Nicomache ?personata	1	112	1	124	X			Annelida	Maldanidae	Dep
113	Eteone pacifica	1	113	1	125	X			Annelida	Phyllodocidae	Carn
114	Pugettia gracilis	1	114	1	126	X			Arthropoda	Majidae	Scav
115	Mysella tumida	1	115	1	127	X			Mollusca	Montacutidae	Susp
116	Transennella tantilla	1	116	1	128	X			Mollusca	Veneridae	Susp
117	Alaria sp. (unident)	1	117	1	129	X			Phaeophyta	Alariaceae	Prim
118	Ampharete labrops	1	118	0			X		Annelida	Ampharetidae	Dep
119	Maldane sarsi	1	119	0				X	Annelida	Maldanidae	Dep
120	Scoloplos armiger	1	120	0			X		Annelida	Orbiniidae	Dep
121	Ophiura lutkeni	1	121	0				X	Echinodermata	Ophiuridae	Scav
122	Tellina nuculoides	1	122	0			X		Mollusca	Tellinidae	Dep
123	Lucina annulata	1	123	0			X		Mollusca	Lucinidae	
124	Terebellides californica	0		40	31			X	Annelida	Trichobranchidae	Dep
125	Americorophium salmonis	0		16	57			X	Arthropoda	Corophiidae	Scav
126	Cerebratulus sp.	0		14	60			X	Nemertea	Lineidae	Carn
127	Clinocardium nuttallii juveniles	0		11	66			X	Mollusca	Cardiidae	Susp

Table 1. continued

#	2000 Organism Rank	2000 Count	2000 Rank	1999 Count	1999 Rank	Both	2000	1999	PHYLUM	FAMILY	TROPHIC
128	Mazzaella splendens	0		11	67			X	Rhodophyta	Gigartinaceae	Prim
129	Pontogeneia ivanovi	0		9	72			X	Arthropoda	Pontogeneiidae	Scav
130	Allorchestes angusta	0		8	76			X	Arthropoda	Hyalidae	Scav
131	Gelidium spp.	0		7	82			X	Rhodophyta		Prim
132	Prionospio multibranchiata	0		4	92			X	Annelida	Spionidae	Dep/Susp
133	Ampelisca agassizi	0		4	93			X	Arthropoda	Ampeliscidae	Scav
134	Fabia subquadrata	0		4	94			X	Arthropoda	Pinnotheridae	Comm
135	Macoma secta	0		4	95			X	Mollusca	Tellinidae	Dep
136	Sargassum muticum	0		4	96			X	Phaeophyta	Sargassaceae	Prim
137	Malacoceros glutaeus	0		3	102			X	Annelida	Spionidae	Dep/Susp
138	Hyale frequens	0		3	103			X	Arthropoda	Hyalidae	Scav
139	Megalorchestia pugettensis	0		3	104			X	Arthropoda	Talitridae	Scav
140	Pinnixia faba	0		3	105			X	Arthropoda	Pinnotheridae	Comm
141	Pinnixia schmitti	0		3	106			X	Arthropoda	Pinnotheridae	Comm
142	Maldanid (unident.)	0		2	113			X	Annelida	Maldanidae	Dep
143	Hemigrapsus nudus	0		2	114			X	Arthropoda	Grapsidae	Scav
144	Amphiodia periercta	0		2	115			X	Echinodermata	Amphiuridae	Scav
145	Crassostrea gigas	0		2	116			X	Mollusca	Ostreoida	Susp
146	Onuphis iridescens	0		1	130			X	Annelida	Onuphidae	Omni
147	Eupolymnia sp. A	0		1	131			X	Annelida	Terebellidae	Dep
148	Magelona hobsonae	0		1	132			X	Annelida	Magelonidae	Dep
149	Dorvillea annulata	0		1	133			X	Annelida	Dorvilleidae	Carn
150	Eulalia parvoseta	0		1	134			X	Annelida	Phyllodocidae	Carn
151	Nephtys sp. (unident.)	0		1	135			X	Annelida	Nephtyidae	Carn
152	Syllis ?stewarti	0		1	136			X	Annelida	Syllidae	Carn
153	Zostera marina	0		1	137			X	Anthophyta	Potamogetonaceae	Prim
154	Scleroplax granulata	0		1	138			X	Arthropoda	Pinnotheridae	Comm
155	Amphiodia urtica	0		1	139			X	Echinodermata	Amphiuridae	Scav
156	Tonicella lineata	0		1	140			X	Mollusca	Lepidochitonidae	Herb
157	Macoma balthica	0		1	141			X	Mollusca	Tellinidae	Dep
158	Cryptomya californica	0		1	142			X	Mollusca	Myidae	Comm
159	Polinices lewisii	0		1	143			X	Mollusca	Naticidae	Carn
160	Desmarestia viridis	0		1	144			X	Phaeophyta	Desmarestiaceae	Prim

Table 1. continued

#	2000 Organism Rank	2000 Count	2000 Rank	1999 Count	1999 Rank	Both	2000	1999	PHYLUM	FAMILY	TROPHIC
161	Caulacanthus sp.	0		1	145			X	Rhodophyta	Caulacanthaceae	Prim
162	Ceramium sp.	0		1	146			X	Rhodophyta	Ceramiaceae	Prim
163	Smithora naiadum	0		1	147			X	Rhodophyta	Erythropeltidaceae	Prim

Table 2. We recommend that the sites sampled in 2000 be sampled again in 2001 using the same protocols to insure temporal consistency. To allow for comparisons of communities between the east and west shores of the Central Basin, we recommend that the same sampling protocols be used. If low taxonomic resolution sampling is attempted this year, then the remaining transects in the Central Sound nearshore cells should be revisited using those protocols. However, it may be determined by WADNR that the best use of low taxonomic resolution sampling will be during the intervening years between high taxonomic resolution sampling.

High-Resolution Sampling Sites

Basin	Location	Cell #	Segment #
South	Budd	7	4
			5
			6
	Case	8	18
			19
			20
	Carr	1	53
			70
			102
Central (east)	Redondo	10	4
			5
			6
	Brace	11	13
			14
			15
	Carkeek	12	22
			23
			24
	Possession	13	31
			32
			33
Central (west)	to be identified		X
			X
			X
			X
			X
			X
			X
			X
			X
			X
			X
			X

Low-Resolution Sampling Sites

Basin	Location	Cell #	Segment #
South	Case	9	15
			16
			17
Central	Brown	10	1
			2
			3
	Normandy	10	7
			8
			9
	Seahurst	11	10
			11
			12
	Alki	11	16
			17
			18
	West Pt	12	19
			20
			21
	Wells	12	25
			26
			27
	Edmonds	13	28
			29
			30
	Double Bluff	13	34
			35
			36

Table 3. Recommended "low resolution" taxa, with rare organisms omitted

Epifauna (identify in field)

Polynoidae (scaleworms)
Sabellidae
Serpulidae

Order Amphipoda
Sphaeromid isopods
Idoteid isopods
Hippolytid shrimp
Class Cirripedia
Cancrid crabs (list species if possible)
Hemigrapsus (list species if possible)
Majid (spider) crabs
Pagurid (hermit) crabs
Xanthid crabs (Lophopanopeus)

Anthopleura spp.
Metridium

Cl. Ophiuroidea (brittle stars)
Leptasterias
Evasterias
Dendraster
Strongylocentrotus

Mopalia spp.
Tonicella
Haminoea slugs
Hermissenda
Onchidoris spp.
Alia spp.
Bittium spp.
Crepidula (list species if possible)
Lacuna spp.
Littorina spp.
Lottiid limpets
Nassarius spp.
Nucella (list species if possible)
Odostomia spp.
Polinices
Calliostoma
Lirularia
Anomiidae (jingle shells)
Mytilus spp.
oysters
Pholadidae (boring clams)

Ph. Nemertea (ribbon worms)
Ph. Platyhelminthes (flatworms)

Epiflora (identify in field)

Zostera marina

green filaments (Acrosiphonia, Cladophora)
green blades and tubes (Ulva, Enteromorpha, Monostroma, Ulvaria)

Alaria sp.
Laminaria spp.
Desmarestia spp.
Fucus spp.
Punctaria
Sargassum
small brown blades and tubes (Scytosiphon, Petalonia)

Porphyra sp.
wirey branched reds (Endocladia, Gelidium, Caulacanthus)
thin red filaments (Polysiphonia, Ceramium, Microcladia)
branched red blades (Mastocarpus, Mazzaella spp., Prionitis)
branched red tubes (Gracilaria, Sarcodiotheca)
Rhodomelaceae (Neorhodomela, Odonthalia)
Encrusting algae

Vertebrates

Cottidae (sculpins)
Stichaeidae (gunnels and pricklebacks)

Table 3, continued. Recommended low-resolution taxa

<u>Infauna (identify later in preserved samples)</u>	
Polychaeta	Capitellidae (maybe separate by species)
	Chaetopteridae
	Cirratulidae
	Dorvilleidae
	Glyceridae
	Goniadidae
	Hesionidae
	Lumbrineridae
	Maldanidae
	Nephtyidae
	Nereidae
	Onuphidae
	Opheliidae
	Orbiniidae
	Oweniidae
	Pectinariidae
	Pholoidae
	Phyllodocidae
	Polynoidae
	Spionidae
	Syllidae
	Terebellidae
	Callianassidae
Crustacea	Upogebiidae
	Sphaeromid isopods
	Pinnotherid crabs
	Tanaidacea
	Edwardsiidae
Cnidaria	Cl. Ophiuroidea
Echinodermata	Synaptidae
	Cardiidae (Clinocardium)
Bivalvia	Hiatellidae
	Lucinidae
	Mactridae (Tresus)
	Myidae
	Tellinidae
	Veneridae
Misc.	Ph. Nemertea
	Ph. Phoronida

Appendix B. All species from Puget Sound database (unidentified taxa omitted) sorted by phylum and family.
( ) = rare, omitted for Table 3.

PHYLUM	FAMILY	SPECIES	Recommended "low resolution" taxa
Annelida	Ampharetidae	Ampharete labrops	Ampharetidae
Annelida	Capitellidae	Capitella capitata	Capitellidae
		Decamastus gracilis	
		Mediomastus californiensis	
		Notomastus lineatus	
		Notomastus tenuis	
Annelida	Chaetopteridae	Spiochaetopterus costarum	Chaeotopteridae
Annelida	Cirratulidae	Aphelochaeta multifilis	Cirratulidae
		Caulleriella ?pacifica	
		Cirratulus cingulatus	
		Cirratulus multioculata(?)	
		Cirratulus robustus	
		Cirriformia sp.A	
		Tharyx parvus	
Annelida	Dorvilleidae	Dorvillea annulata	Dorvilleidae
Annelida	Flabelligeridae	Pherusa plumosa	(Flabelligeridae)
Annelida	Glyceridae	Glycera americana	Glyceridae
		Glycera siphonostoma	
		Glycera tenuis	
		Glycinde polygnatha	
		Hemipodus borealis	
Annelida	Goniadidae	Glycinde picta	Goniadidae
		Goniada annulata	
Annelida	Hesionidae	Kefersteinia sp.	Hesionidae
		Micropodarke dubia	
		Podarke pugettensis	
		Podarkeopsis glabrus	
Annelida	Lumbrineridae	Lumbrineris pallida	Lumbrineridae
		Lumbrineris zonata	
Annelida	Magelonidae	Magelona hobsonae	Magelonidae
Annelida	Maldanidae	Axiothella rubrocincta	Maldanidae
		Euclymene sp.A	
		Euclymene sp.B (cf. zonalis)	
		Maldane sarsi	
		Nicomache ?personata	
Annelida	Nephtyidae	Nephtys caeca	Nephtyidae
		Nephtys caecoides	
		Nephtys ferruginea	
		Nephtys longosetosa	
Annelida	Nereidae	Nereis brandti	Nereidae
		Nereis limnicola	
		Nereis procera	
		Nereis vexillosa	
		Nereis zonata	
		Platynereis bicanaliculata	
Annelida	Onuphidae	Diopatra ornata	Onuphidae
		Nothria conchylega	
		Onuphis 'holobranchiata'	
		Onuphis iridescens	

Appendix B, continued

PHYLUM	FAMILY	SPECIES	Recommended "low resolution" taxa
Annelida	Opheliidae	Armandia brevis	Opheliidae
Annelida	Orbiniidae	Leitoscoloplos pugettensis	Orbiniidae
		Scoloplos armiger	
Annelida	Oweniidae	Owenia fusiformis	Oweniidae
Annelida	Pectinariidae	Pectinaria granulata	Pectinariidae
		Pectinaria moorei	
Annelida	Pholoidae	Pholoe minuta =? P. glabra	Pholoidae
Annelida	Phyllodocidae	Eteone pacifica	Phyllodocidae
		Eulalia parvoseta	
Annelida	Pilargiidae	Sigambra tentaculata	(Pilargiidae)
Annelida	Polynoidae	Harmothoe imbricata	Polynoidae
		Hesperonoe complanata	
		Lepidonotus squamatus	
		Malmgreniella bansei	
		Malmgreniella nigralba	
Annelida	Sabellidae	Sabellid (unident.)	Sabellidae
Annelida	Serpulidae	Serpulid sp. (unident.)	Serpulidae
Annelida	Spionidae	Boccardiella hamata	Spionidae
		Malacoceros glutaeus	
		Paraprionospio pinnata	
		Polydora brachycephala	
		Polydora cardalia	
		Polydora columbiana	
		Polydora kempi japonica	
		Polydora socialis	
		Prionospio multibranchiata	
		Prionospio steenstrupi	
		Scolelepis squamata	
		Spio filicornis	
		Spiophanes berkeleyorum	
		Spiophanes bombyx	
Annelida	Syllidae	Syllis ?stewarti	Syllidae
		Syllis heterochaeta	
Annelida	Terebellidae	Eupolymnia sp. A	Terebellidae
		Neoamphitrite robusta	
		Nicolea zostericola (?)	
		Pista wui	
		Polycirrus n. sp. (L. Harris)	
Annelida	Trichobranchidae	Terebellides californica	(Trichobranchidae)
		Terebellides stroemii	
Arthropoda	Ampeliscidae	Ampelisca agassizi	Order Amphipoda
Arthropoda	Ampithoidae	Ampithoe dalli	
Arthropoda	Ampithoidae	Ampithoe lacertosa	
Arthropoda	Anisogammaridae	Anisogammarus pugettensis	
		Eogammarus oclairi	
Arthropoda	Archaeobalanidae	Semibalanus cariosus	Class Cirripedia
Arthropoda	Balanidae	Balanus glandula	
Arthropoda	Callianassidae	Neotrypaea californiensis	Callianassidae
Arthropoda	Cancridea	Cancer spp.	Cancrid crabs (identify species if possible)
Arthropoda	Corophiidae	Americorophium salmonis	Order Amphipoda
		Monocorophium acherusicum	

Appendix B, continued

PHYLUM	FAMILY	SPECIES	Recommended "low resolution" taxa
Arthropoda	Sphaeromatidae	Exosphaeroma inornata	Sphaeromatid isopods
		Gnorimosphaeroma oregonense	
Arthropoda	Grapsidae	Hemigrapsus nudus	Grapsid crabs (identify species if possible)
		Hemigrapsus oregonensis	
Arthropoda	Hippolytidae	Heptacarpus sitchensis	Hippolytid shrimp
		Hippolyte clarki	
Arthropoda	Hyalidae	Allorchestes angusta	Order Amphipoda
		Hyale frequens	
Arthropoda	Idoteidae	Idotea sp.	Idoteid isopods
Arthropoda	Ligiidae	Ligia occidentalis	(Ligiidae)
Arthropoda	Majidae	Pugettia gracilis	Majid crabs
Arthropoda	Paguridae	Pagurus spp.	Paguridae
Arthropoda	Pinnotheridae	Fabia subquadrata	Pinnotheridae
		Pinnixia eburna	
		Pinnixia faba	
		Pinnixia schmitti	
		Pinnixia tubicola	
		Scleroplax granulata	
Arthropoda	Pontogeneiidae	Pontogeneia ivanovi	Order Amphipoda
Arthropoda	Talitridae	Megalorchestia pugettensis	Order Amphipoda
Arthropoda	Tanaidacea	Leptochelia dubia	Tanaidacea
Arthropoda	Upogebiidae	Upogebia pugettensis	Upogebiidae
Arthropoda	Xanthidae	Lophopanopeus bellus bellus	Xanthid crabs
Chordata	Cottidae	Oligocottus maculosus	Cottidae
Chordata	Stichaeidae	Anoplarchus purpurescens	Stichaeidae
Chordata		Gunnel (unident.)	
Cnidaria	Actiniidae	Anthopleura elegantissima	Anthopleura
Cnidaria	Edwardsiidae	Edwardsia sipunculoides	Edwardsiidae
		Edwardsia sp.	
Cnidaria	Metridiidae	Metridium senile	Metridium
Echinodermata	Amphiuridae	Amphiodia periercta	Cl. Ophiuroidea
		Amphiodia urtica	
		Amphipholis squamata	
Echinodermata	Asteriidae	Evasterias troschelii	Evasterias
		Leptasterias hexactis	Leptasterias
Echinodermata	Dendrasteridae	Dendraster excentricus	Dendraster
Echinodermata	Ophiuridae	Ophiura lutkeni	Cl. Ophiuroidea
Echinodermata	Strongylocentrotidae	Stronglyocentrotus droebachiensis	Strongylocentrotus
Echinodermata	Synaptidae	Leptosynapta clarki	Synaptidae
Hemichordata	Unid	Saccoglossus sp.	(Ph. Hemichordata)
Mollusca	Anomiidae	Pododesmus cepio	Anomiidae
Mollusca	Atyidae	Haminoea vesicula	Haminoea
Mollusca	Calyptraeidae	Crepidula dorsata	Crepidula spp. (identify to species if possible)
		Crepidula fornicata	
Mollusca	Cardiidae	Clinocardium nuttallii	Cardiidae
Mollusca	Cerithiidae	Bittium eschrichtii	Cerithiidae
Mollusca	Columbellidae	Alia gausapata	Columbellidae
Mollusca	Facelinidae	Hermissenda crassicornis	Facelinidae
Mollusca	Hiatellidae	Hiatella arctica	Hiatellidae
		Panomya chrysis	
Mollusca	Lacunidae	Lacuna vincta	Lacunidae

Appendix B, continued

PHYLUM	FAMILY	SPECIES	Recommended "low resolution" taxa
Mollusca	Lepidochitonidae	Tonicella lineata	Tonicella
Mollusca	Littorinidae	Littorina scutulata	Littorinidae
Mollusca	Lottiidae	Lottia pelta	Lottiidae
		Lottia strigatella	
		Tectura scutum	
Mollusca	Lucinidae	Lucina annulata	Lucinidae
		Lucina tenuisculpta	
Mollusca	Mactridae	Tresus capax	Mactridae
Mollusca	Montacutidae	Mysella tumida	Montacutidae
		Pseudopythina rugifera	
Mollusca	Mopaliidae	Mopalia lignosa	Mopalia spp.
Mollusca	Myidae	Cryptomya californica	Myidae
		Mya arenaria	
Mollusca	Mytilidae	Mytilus trossulus	Mytilidae
Mollusca	Nassariidae	Nassarius mendicus	Nassariidae
		Nassarius perpinguis	
Mollusca	Naticidae	Polinices lewisii	Naticidae
Mollusca	Nucellidae	Nucella canaliculata	Nucella (identify to species if possible)
		Nucella lamellosa	
Mollusca	Onchidorididae	Onchidoris bilamellata	Onchidoris
Mollusca	Ostreoida	Crassostrea gigas	oysters
		Ostrea edulis	
		Ostrea lurida	
Mollusca	Pholadidae	Piddock clam (unident.)	Pholadidae
Mollusca	Pyramidellidae	Odostomia sp. (unident.)	Odostomia
		Turbonilla sp. (unident.)	
Mollusca	Tellinidae	Macoma balthica	Tellinidae
		Macoma inquinata	
		Macoma nasuta	
		Macoma secta	
		Tellina bodegensis	
		Tellina modesta	
		Tellina nuculoides	
Mollusca	Trochidae	Calliostoma sp.	Calliostoma
		Lirularia succincta	Lirularia
Mollusca	Veneridae	Compsomyax subdiaphana	Veneridae
		Protothaca staminea	
		Saxidomus giganteus	
		Tapes philippinarum	
		Transennella tantilla	
Nemertea	Emplectonematidae	Paranemertes peregrina	Ph. Nemertea
Nemertea	Lineidae	Cerebratulus sp.	
Nemertea		Nemertean (unident.)	
Phoronida	Phoronidae	Phoronopsis harmeri	Ph. Phoronida
Platyhelminthes	Childiidae	Freemania litoricola	Ph. Platyhelminthes
Platyhelminthes		Flatworm (unident.)	
Sipuncula	Phascolosomatidae	Phascolosoma agassizii	(Ph. Sipuncula)

Appendix B, continued

PHYLUM	FAMILY	SPECIES	Recommended "low resolution" taxa
Anthophyta	Potamogetonaceae	Zostera marina	Zostera marina
Chlorophyta	Acrosiphoniaceae	Acrosiphonia coalita	green filaments
Chlorophyta		Ulvoids (unident.)	green blades and tubes
Phaeophyta	Alariaceae	Alaria sp. (unident)	Alaria sp.
Phaeophyta	Desmarestiaceae	Desmarestia viridis	Desmarestia spp.
Phaeophyta	Fucaceae	Fucus gardneri	Fucus spp.
Phaeophyta	Laminariaceae	Laminaria saccharina	Laminaria spp.
Phaeophyta	Punctariaceae	Punctaria expansa	Punctaria
Phaeophyta	Sargassaceae	Sargassum muticum	Sargassum
Phaeophyta	Scytosiphonaceae	Scytosiphon lomentaria	small brown blades and tubes
		Petalonia fascia	
Rhodophyta	Bangiaceae	Porphyra sp.	Porphyra sp.
Rhodophyta	Caulacanthaceae	Caulacanthus sp.	wirey branched reds
	Endocladiaceae	Endocladia muricata	
	Gelidiaceae	Gelidium spp.	
Rhodophyta	Ceramiaceae	Ceramium sp.	thin red filaments
		Microcladia borealis	
	Rhodomelaceae	Polysiphonia sp. (unident.)	
Rhodophyta	Erythropeltidaceae	Smithora naiadum	(Smithora)
Rhodophyta	Gigartinaceae	Mazzaella heterocarpa	branched red blades
		Mazzaella splendens	
Rhodophyta	Halymeniaceae	Prionitis sp. (unident.)	
Rhodophyta	Petrocelidaceae	Mastocarpus papillatus	
Rhodophyta	Gracilariaceae	Gracilaria pacifica	branched red tubes
	Solieriaceae	Sarcodiotheca sp. (unid.)	
Rhodophyta	Rhodomelaceae	Neorhodomela larix	Rhodomelaceae
		Odonthalia floccosa	
		Encrusting algae (unid.)	Encrusting algae